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Behavioral Cross Check method

DATE: 28/10/2022

Summary

This document aims to explicit and to explain the designed method called "Behavior Cross Check" (BCC). This method is introduced by the top document framed by the S2C project.

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This method is based on the concept of "Cross Check of observations" done on the simulation results of two distinct models. The document includes the description of the proposed method, two proof of concept (PoC) based upon SE and SA models to experiment and validate the method and the conclusions of the method.

Author(s)	Function(s) & name(s)	Research engineers IRT Saint Exupéry	S. Guilmeau
Checker(s)	Function(s) & name(s)	Head of Systems Engineering Centre of Competence IRT Saint Exupéry	J. Baclet
Approver	Function & name	Project leader IRT Saint Exupéry	J. Perrin

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Evolutions

Version	Date	Modified §	Modification summary	Modified by
1	06/01/2022	All	Creation	AGB/SG
2	10/02/2022	See technical note	NT-S085-L02T00-027	AGB/SG
3	17/03/2022	See technical note	NT-S085-L02T00-028	AGB/SG
4	10/06/2022	§2.2.1	Transferred to TOP V4 originated from remarks done on BCC V2	SDU/JDS/AG/SG
		§5	Added to introduce PoC	
5	13/07/2022	§2.2.1, §2.3.1	Remove redundant drawings already present in TOP V4	SDU/JDS/AGB/SG
		§3.1.1.a	Treat back logged remark done NT-S085- L02T00-028	
		See technical note	NT-S085L02T00-032	
6	28/10/2022	§1.1.2 §5 (intro only)	Update (minor) reference of extern documents Add table of model versions	33



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1 Introduction

1.1 Purpose of document

This document aims to explain the BOC method and to demonstrate its use through several Proofs of concept (PoCs). The working group dealing with BOC is the second one (called lot2) defined as per document ODP-S-085-063-VO.

As announced and explained in Section 2.3 of LIV-S085L02-007-V6, ISX-S2C-LIV-1037-V6, the document includes the following parts:

Section 2 exposes the context, objective and constraints that method shall consider,

Section 3 exposes the method and its adaptation regarding what the previous section exposes,

Section 4 exposes foreseeable consequence of method as intermediate conclusion before Proof of Concepts are done. Section 5 exposes the assessment with PoC and associated adaptions (if any),

Protion C composes the accountern with robuind accounted adaptions (in air)

Section ${\bf 6}$ exposes the conclusions of the method regarding its assessment.

1.2 Referenced documents

1.2.1 S2C reference documents

Title	Reference
Method to ensure and to maintain consistency of systemic levels & Validation report MBSE/MBSA consistency	ШV-\$085L02-007-V6, ISX-\$2C-ШV-1037-V6
OONTRAT DE PROJET DE RECHERCHE EN PROPRE Pour la réalisation du PROJET S2C System & Safety Continuity	CDP-S-085-063-V0

1.2.2 External reference documents

Title	Reference
Aerospace Recommended Practice - Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment, 1996	ARP4761
Aerospace Recommended Practice - Guidelines For Development Of Ovil Aircraft and Systems, Revision A, 2010	ARP4754A
Model-based System and Architecture Engineering with the Arcadia Method, ${\bf L}$ Voirin, 2017	ARCADIA
SysML specification, Object Management Group, V1.6, 2019	SYSML
Semantics of a fundamentals Subset for Executable UML Models specification, Object Management Group, V1.5, 2021	fUML
Precise Semantics of UML Composite Structures, Object Management Group, V1.2, 2019	PSCS
Precise Semantics of UML State Machines, Object Management Group, V1.0, 2019	PSSM

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2 Objectives, constraints and Context

2.1 Objectives

The items #id-4 and #id-8 of Table 6 of LIV-S085L02-007-V6, ISX-S2C-LIV-1037-V6 allocate to BOC

- #id-a BCC them because user wants to see the effect at the system level and not locally as for the BSR (Behavior Scoped Review see LIV-S085L02-007-V6, ISX-S2C-LIV-1037-V6) method,
- #id-b: Here, the "execution" part of the statement is to be taken regarding its concept, and independently from the actual simulation capabilities of the authoring tool (e.g. CAPELLA has not this one). This execution may be for example a human reasoning process, or the automatic simulation of a model.
 - #id-c The execution of the model can provide information on its structure: what are (or what shall be) the functions called during execution". It can also provide information on the behavior: what are (or what shall be" the values of interfaces (final or intermediate ones in the system) during the

Note: the item #id-c (about execution), uses the observations on control and data flows, like what is done during system development, as they contribute to the behavior. So the consistency have to be stated regarding the matching of expecting flows and values (independently if they are data or control) between models.

2.2 Constraints

•

2.2.1 Common constraints

U 5 of LIV-S085L02-007-V6, ISX-S2C-LIV-1037-V6 are reuse to trace compliance against this method all along the document so #id-d, ,#id-e, #id-f, #id-g, #id-j, #id-k, #id-l, #id-m, #id-n, #id-o are use for this tracing.

Note: The BCC method take care of constraint **#id-g**, because discarding it, make easy to constraint users to model in such manner that any method can be artificially applicable.

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2.3 Context

2.3.1 Common Context

The Section 2.2 of LIV-S085L02-007-V6, ISX-S2C-LIV-1037-V6, sets the momentum where method shall be used, so PSSA (for acronyms see §2.3 of ARP4761) is kept for this method.

The Section 3.1 of LIV-S085L02-007-V6, ISX-S2C-LIV-1037-V6 about position the methods against the company processes

2.3.2 Specific Context

No specialization regarding common context is considered for this method.



3 Developed method

Section 3.2.3 of document LIV-S085L02-007-V6, ISX-S2C-LIV-1037-V6 introduces briefly the BOC. So following sections aim to detail it, to define used words and their relations against BOC process and to trace method artefacts against constraints exposed in Section 2.2. For this last purpose, a traceability matrix follows each paragraph to make the link between the described method activity and the listed constraints. In this matrix, black cell is used when a constraint is considered as not applicable for the activity.

3.1 BCC Process

BCC borrows its basis from the system test strategy, similar to integration tests where some end to end tests are executed to check that components correctly (regarding the test objective) exchange and behave as it is planned for SE specialist. It must be noticed that this is not unit test strategy of system components where all behavior are tested.

So this strategy is applied to the problem of behavioral consistency between models as follows: if two models behave the same expected way in the same expected context, it means they are probably consistent for this context.

The difficulties are on:

- the access to behaviors in each model considering their different abstraction levels,
- the insurance that their contexts are the same.

model execution into a given

First difficulty is solved through the observations model excontext. Second one is solved when implementation contexts considered to be equivalent.

This equivalence sthe hard point. BCC approach consists in starting from a conceptual common context, where each stakeholder know and share the same objectives and semantic (called scenario). Then they decline it into their own implementation contexts relying on their authoring method and tools (called procedure). So, if each stakeholder get what they expect in term of observed values with their means (after execution of their procedure), then the behaviors exercised are said consistent for this scenario. Scenario may be declined in different procedures for the same domain regarding if different situations are to behave the same way.

If observations done during at least one of the two procedures do not match expectations, this is a discrepancy. Both stakeholders shall analyze any discrepancy then have a status and a rationale associated to it.

In order to ease the comprehension of the method, process splits into three parts:

- the scenario initialization,
- the scenario exploitation,
- the scenario final status on consistency.

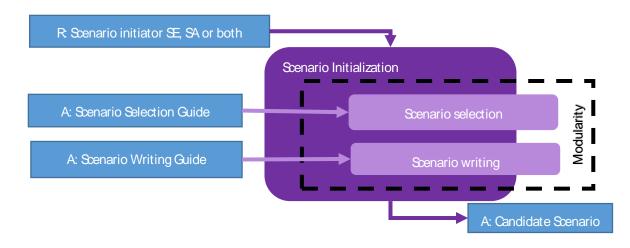


Each part is composed of activities using artefacts and resources (SE and/or SA specialists) that support realization and maintenance (called iterations).



3.1.1 Scenario initialization

The scenario initialization is the first part and its objective is to get a scenario agreed by both SE and SA for the rest of the process. It is composed of two activities: scenario selection and writing activity. Both activities are concerned with modularity constraint. Hereafter, a synopsis to sum up:



(a) Scenario selection

This activity allows you to decide both of which scenario to address in the next part of method.

It requires a (#id-m) to give the targeted kind of scenarios that may detect behavioral discrepancies. These directives are versatile as they depend on the context of design where the system is (e.g. scenarios for a new risky function are more sensible at start of design than scenario for already known function, severity of effect of function can be another and more long term directive). also include the constraints that exist all along

the process and subsequent activities (counter example: there is no reason to select a scenario that is not doable). So, it will lead to scenarios that are suitable and achievable by both SE and SA specialists to t

(#id-a). This means, partial scenarios (those covering a nested part of the system) will be discarded, as they do not meet end to end criteria. It shall select scenarios also according to implementation and simulability means available (#idh). Selection of scenario can also be driven by SA cutsets (if available after setup of SA model).

It should be noticed that this activity does not aim to replace any activity already being part of the current activities held by \mathfrak{E} and \mathfrak{SA} (#id-j). In other words, \mathfrak{SA} can use its \mathbb{HA} process to identify some scenarios, but performing this selection activity, will not change or impact what \mathfrak{SA} has to do with the \mathbb{HA} (#id-k). Same for \mathfrak{E} , it selects its scenario considering what shall not vary during its architecture changes or what has to be derisked.

This selection activity and artifact can integrate any company current processes (#id-o) already providing similar outputs and they can tailor them capabilities (#id-n). However whatever how the way method is integrated with company process, selection shall be formalized and kept up to date to avoid what is the aim

Regarding the initiator of this activity (#id-i), the issue is treated in section Modularity

Inversely to what is stated in (#id-g) it is impossible to select a scenario for which no model is implemented). Moreover, being an intermediate activity mandatory for the process, it does not minimize the effort for the resources. In fact it adds as well the Selection Guide artefact to be managed too (#id-I).

Method artefact	#id-a	d-bi#	#id-c	#id-d	#id-e	#id-f	#id-g	h-bi#	#id-i	#id-j	#id-k	#id-l	#id-m	#id-n	#id-o	#id-p
Selection act.	\checkmark						\checkmark									

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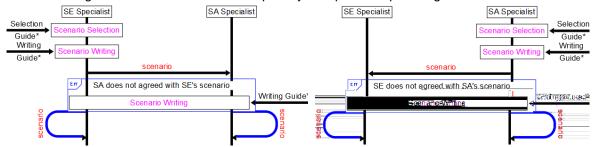


(c) Modularity

The method takes into account the constraint that either SE or SA or both may be capable of starting and leading the process (#id-i). Thus, there are three possibilities regarding the resources involved in the scenario for the scenario initialization phase:

- SE (resp. SA) specialist proposes a scenario following the Selection Guide. He/ She is de facto the leader of the activity for this scenario. Then, he/ she writes its following directives stated in the Writing Guide. When the scenario is ready, it is transferred to SA (resp. SE) and asks for agreement. If SA (resp. SE) does not agree, then a meeting must be held. During meeting discussion, the scenario:
 - can be rejected and the selection guide updated to keep the status (and avoid to propose again a similar scenario,
 - o can be amended (or rewritten together).

After the meeting the scenario is considered accepted by both parts and process goes on.



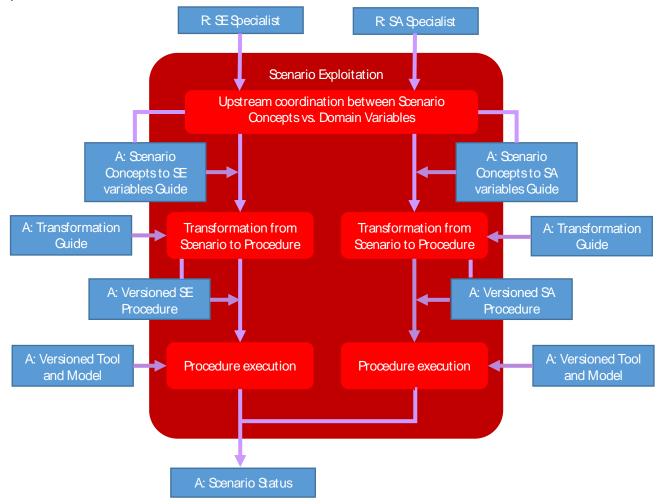
• SE and SA propose together a scenario during a meeting: the leadership on this situation is shared between SE and SA. When agreement is shared, the rest of process can treat the scenario. As others dispositions, this one requires the use of both Selection Guide and Writing Guide too.





3.1.2 Scenario exploitation

The scenario exploitation is the core part of the process and its objective is to deliver a status of the scenario to the rest of the process. This part is composed of activities: variables and values coordination, transformation from scenario to procedure and execution of procedure. Hereafter, a schema of the activities and involved input and output artefacts is presented.



(a) Upstream coordination between Scenario Concepts vs. Domain Variables

Upstream coordination between scenario concepts versus domain variables and values activity is mandatory for behavioral coherence between SE and SA models, as it is part of its own definition and define context talked in Section 3.1.

Hereafter, a schema of the involved resources, input and output artefacts is presented:





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Starting from SE and SA models (#id-e), this coordination activity gathers the following objectives to ensure everyone is comparing the same objects and be able to find any discrepancies (#id-d) in both structural and behavioural aspects (#id-c):

- Coordinate semantic content between variables from \mathfrak{E} and SA models: different names can be selected for \mathfrak{E} and SA to refer to a same concept. Thanks to this activity, they are making the association.
- Identify considered hypothesis: some hypothesis may be made in SE and SA models, not necessarily shared by each other. It serves as the opportunity to share the assumptions with the other part and to evaluate the impact on the concepts that appear in the scenario.
- Anticipate, for each part (SE and SA), the declination into procedure to cover the scenario: performing this coordination activity is essential for the declination to a procedure after.
- List values and variables correspondences representing the same concept: it evaluates the variables and values that \mathfrak{E} and SA target to correspond to scenario concepts.
- Evaluate behaviour of external system elements modelled in \mathfrak{E} and SA: there may be some external elements from the system itself that have been modelled in \mathfrak{E} and/or SA models to cover some modelling needs or simplify the whole comprehension. It is, at this point, that the behavior of these modeled artifacts and the impact they may have in the end-to-end scenario (#id-a) must be shared with the other party.

This activity can be supported by a table (database or other format) that summarizes all the information related to the objectives listed above. It requires the participation of SE and SA resources and may need various exchanges between them until all scenario concepts are fully addressed in that table and are associated to both SE and SA artefacts. Therefore, (#id-j) with IVV activities.

Concerning modelling constraints (#id-g), this activity may need to introduce some modifications into the models to coordinate with the other model, thus it does not minimize modeling constraints at all. Depending on the choice made on (#id-h), it will have an impact on the coordination activity: for example, if behavior is modelled, it will obligate to coordinate until this level whilst if execution is not considered, the coordination activity will be of lower charge.

It should be noted that the upstream coordination activity is needed for the process and it does not minimize the effort for the resources (#id-I), in fact it adds as well the Coordination Table artefact to be managed. Moreover, any choices done on this activity may have an impact in the rest of the modelling artefacts and the scenario may need to be rewritten in some cases.

This coordination activity and related artefacts can integrate any current company processes (#id-o) already providing (#id-n). However, it should be noted that any

divergence from what the method is proposing may impact the final confidence confidence level on consistency. Regarding constraint (#id-p), for the sequences #sq-2 and #sq-4, where SSR and BSR respectively have been performed

Method artefact	#id-a	d-bi#	#id-c	#id-d	#id-e	#id-f	#id-g	#id-h	#id-i	#id-j	#id-k	#id-l	#id-m	#id-n	#id-o	#id-p
Upstream Coordination act.	\checkmark		\checkmark	\checkmark	\checkmark		\checkmark	\checkmark		\checkmark	\checkmark	\checkmark		\checkmark	\checkmark	\checkmark

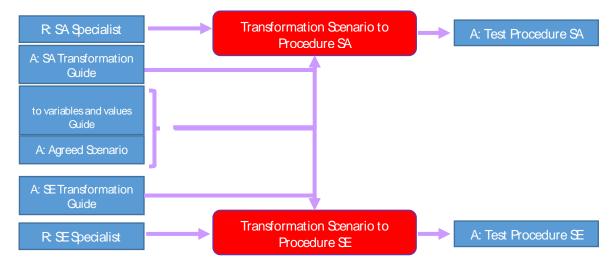
Note: constraint (#id-k) is still applicable and inherited by the scenario initialization activities.



(b) Transformation from Scenario to Procedure

This activity transforms agreed scenario to a sequence of « steps » (of actions and observations) creating one or more procedures that must be executed with the \mathfrak{E} or SA means, taking into account its simulability and implementation degrees (#id-h). This is an independent activity and parallel activity between \mathfrak{E} and SA. This means that there must be a transformation for \mathfrak{S} and a transformation for SA (#id-e) from the same scenario. Concerning (#id-j), it fully depends on users experience and participation in IVV activities and in this type of transformation activity.

Hereafter, a schema of the involved resources, input and output artefacts is presented:



. This artifact gives the

directives to follow when transforming the scenarios into procedures in order to unify the format and to obtain valid procedures to be executed in both SE and SA environments, related to both structural and behavioural aspects (#id-c) (#id-a)

resources, and it has to be maintained in time according the evolutions that may appear during the process lifetime.

It should be noted that the transformation from scenario to procedure activity is needed for the process and it does not minimize the effort for the resources (#id-I)

This transformation activity and related artifacts can integrate any company current processes (#id-o) already providing similar processes like I (#id-n). However, it should

be noted that any divergence from what the method is proposing may have an impact into final confidence level on consistency.

Note: constraint (#id-k) is still applicable and inherited by the scenario initialization activities.

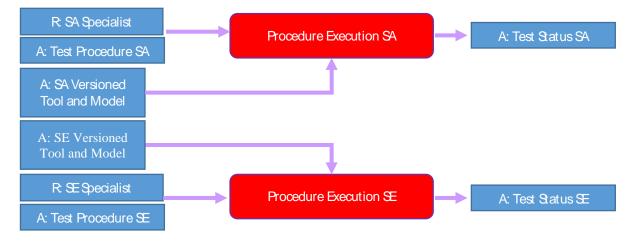
Method artefact	#id-a	d-bi#	#id-c	#id-d	#id-e	#id-f	#id-g	h-bi#	i-bi#	j-bi#	#id-k	#id-l	#id-m	#id-n	#id-o	d-bi#
Transformation act.	\checkmark		\checkmark		\checkmark			\checkmark		\checkmark	\checkmark	\checkmark		\checkmark	\checkmark	



(c) Procedure execution

The procedure execution activity is an independent and parallel activity between \mathfrak{E} and \mathfrak{SA} (#id-e). Each one executes its procedure, previously transformed, with its own tools and models. It gives as an output the scenario status that will serve as a main indicator to extract a conclusion from the scenario at the end of the method.

Hereafter, a schema of the involved resources, input and output artefacts is presented:



However, a

Specific constraints

(#id-i) during execution activity

can be null, semi or full simulable. The selected simulability degree will further have an impact on the confidence regarding the consistency status that will be delivered.

This activity executes the procedures on the version of the tool and the model specified previously in each procedure for \mathfrak{X} and \mathfrak{A} respectively. Tool and model versions then need to be managed accordingly to allow \mathfrak{X} and \mathfrak{A} execute their procedures at the right time in an (#id-a) and for behavioural and structural aspects (#id-c). It will depend on users experience and participation on IVV activities for the easy adaptation of \mathfrak{X} and \mathfrak{A} to this type of execution activity (#id-j).

Regarding (#id-b), method can be used even if authoring tools are not executable but the confidence into the result their mind, hoping that they all "execute" the same

semantics. This can be acceptable for simple or well-known systems but may be considered with caution in other cases. Concerning modelling constraints (#id-g), this activity may identify the need to introduce some modifications into the models, thus it does not minimize at all the modelling constraints.

It should be noted that the procedure execution activity does not minimize the effort for the resources (#id-l). In fact, it adds as well the test procedures and the tools and model versions artefacts to be managed. However, this execution activity and related artifacts can integrate any current processes (#id-o) already providing similar processes like IVV activities, and they can tailor them regar (#id-n).

Note: constraint (#id-k) is still applicable and inherited by the scenario initialization activities.

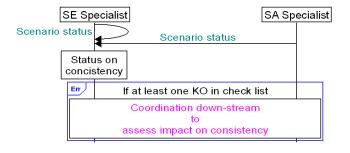
Method artefact	#id-a	d-bi#	#id-c	#id-d	#id-e	#id-f	#id-g	#id-h	#id-i	#id-j	#id-k	#id-l	#id-m	#id-n	#id-o	#id-p
Execution act.	\checkmark	\checkmark	~		~		~	~		\checkmark	\checkmark	\checkmark		\checkmark	~	



3.1.3 Scenario conclusion

The scenario conclusion is the last part of the process and its objective is to give a final status regarding the consistency and the level of confidence in the scenario. It is important to remark that it is not only the scenario status received as an input from previous steps that determines the final status of consistency of the scenario, but also that other parameters have a notable influence on this conclusion. The status of discrepancies (#id-d) appears only after cross checking the result of each domain execution against what was agreed during scenario activities (#id-f). It shall be noticed that the tracking of status fosters usage of version control system (#id-m).

As shown in Figure 10, the scenarios conclusion is mainly composed of one activity, which is the status on consistency. Status on consistency activity uses a checklist to evaluate the outputs on each part of the process for a given scenario, and other information regarding the artifacts used and validation activities (see Section 3.2) that may have been done at any moment all along the process. By completing this checklist, scenarios initiator has a better idea of the status of consistency and its level of confidence. For example, if a Transformation Guide does not exist (or checkers reveal bad use of it) during the transformation of concepts into scenario activity, the final level of confidence will be lower than if a Guide was used properly.



identified. Therefore, an activity shared with both SE and SA dedicated to assess the impact of these s consistency status is needed. Consequently, this activity may identify the need to introduce some modifications into the models, thus it does not minimize at all the modelling constraints (#id-g).

It should be noted that scenario conclusion activity does not minimize the effort for the resources (#id-I). In fact it adds as well the test procedures and the tools and model versions artefacts to be managed. However, this execution activity and related artifacts can integrate any current processes (#id-o) already providing similar processes like IVV activities. T (#id-n) and on users experience for the easy adaptation

of SE and SA to this type of conclusion activity (#id-j).

Note: constraints (#id-a), (#id-c), (#id-e), (#id-k), are still applicable and inherited by the scenario initialization activities.

Method artefact	#id-a	d-b#	#id-c	#id-d	#id-e	#id-f	#id-g	#id-h	#id-i	#id-j	#id-k	#id-l	#id-m	#id-n	#id-o	#id-p
Downstream Coordination act.	\checkmark		\checkmark	\checkmark	\checkmark	\checkmark	\checkmark			\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	



3.2 Intra-process validation activities

The process presented in previous sections is composed of many activities and artifacts. If some of them are not correct consistencies and will give to the result a good

level of achievement about consistency when, in reality, it is not.

A way to reduce the risk o

level, is to perform some validation activities. These validation activities can be done by the same person in charge of the process activity (Auto validation) or by an external actor to the process activity (Alter validation). The first case relies done and

performer can be caught by the other actor.

The choice of Auto or Alter validation has an impact on final confidence level but as also has an impact on cost and resource planning. A trade-off shall be done whether which strategy is the more accurate regarding the context of design and objectives given for the consistency checking. Not all the activities have to take the same kind of validation at the same moment. The allocation of when and what kind of validation by whom, etc., relies on projects needs and constraint: not on the method itself.

The validation activities can be done as a review of the procedure after its transformation from the written scenario, or a re-execution of the procedure to verify the repeatability of the observations, etc. It may be noticed that these validation activities may also be performed by a tool if the possibility exists inside the enterprise implementing the method. The qualification (or not) of the tool is dependent of the method confidence targeted. Such tools can verify the correctness of syntax used (against the guides for example), detect misuse of concepts or inappropriate coordination from the table (in case where SSR or BSR is sequenced before), etc. The more formal the grammar used for writing the scenario and the procedure, the more possible the use of a tool is. If the majority of artefacts are handwritten, then more human will be required as external actor.

It shall be noticed, as scenario is agreed between both specialists, the artefacts are de facto alter validated regarding who initiate the scenario (this is not the case of procedures that are domain and tool specific).

Depending of the integration of the method with company processes, especially those done during development or IVV, the validation strategy can contribute to the corresponding plan. If the method is considered external to these processes the auto or alter validation is at the project discretion and becomes an optional activity (i.e. that can be not done if needed).

The orchestration, phasing or planning of the validation activities are not part of the method as they are similar to any development ones.



3.3 Iterations

The method is impacted when any of its inputs (or artefacts) changes. These are listed below:

N	Nethod artefact
Ir	nput models (SE or SA)
S	Pelection Guide
V	Vriting Guide
S	Benario
C	Concept to variables table
Т	Transformation guide
Ρ	Procedure (SE and SA)

Two opposite approaches for the management of impacts can be used:

- The brutal way: that consists to replay each procedure regarding former results (whatever changes are). If no discrepancies are detected that means the changes have no impact on behavior. But if discrepancies are detected that means changes have impact and SE and SA specialists have to analyze each root cause to point changes that are the origin of the failing procedures. Then, specialists have to downstream the change until the replay of procedure passes again. This approach ensures non-regression of existing behavior. If change consists on adding a new behavior, a new scenario and associated procedures have to be done because it does not exist previous results to be compared with.
- The surgery way: based upon analysis of any known change of them onto the models. Only procedures thought to be replayed are concerned. This way is tightly coupled with version and change management as any change on artefact shall be traced and relayed to the methods. This approach is often use in system development so method may use **already ex0st005(to)** mpany process. This will affect the management and change artefact that will have new field to fill by user to ensure traceability for analysis.

As **#id-I** requires minimization of the effort to maintain artefact, the second approach is not optimal as it requires many traceability (to be done and maintained) between artefacts to ensure the correct downstreaming of modification. First approach is viable only if tools can be chained together. This is a simila8 TJ-4(s)5(.)] TJETQq0.000008871 0 595.32 841.92 reW*nB*



4 Deductible facts before PoCs are done

The present method is very similar to what happens during IVV activities on bench means. Performers specify and play integration tests but, here, it is during system design phase that the method considers the approach. An advantage of this phase is the flexibility that IVV does not have regarding development credential required.

It is also similar to performance specialty when flight tests briefings are established to get telemetry observations of system during flight to compare them with those recorded on the bench. These activities aim to keep consistent the system and models used on ground.

Those last two considerations fulfill transversal constraints like (#id-j or #id-n) because companies are already doing such work (actually lately in the development process) but tools and skills are already present but they are not used during design phase by companies while they can do so.

A positive side effect to apply such method is the preparation of IVV activities that will lower its cost (e.g. because of the availability of operational scenarios during design phase, they are reusable to feed procedure implementation on bench means to proof non-regression of implemented system).

The coverage of all behaviors is not reachable for complex systems as it will require a scenario per behavior to cross check. Furthermore, cross-checks shall be done in different initial condition in SE domain side to reduce risk on corner case. Eg. during flight test, scenario played in a particular point of the flight domain is insufficient to guarantee that it is true is another flight domain point.

Method is not a zero effort cost but many of them can be softened by use of appropriate tools and formalization scripting. Unfortunately, each system and company has its own specifity that induces the need of dedicated layer of specialization upon common testing framework to be efficient. Efficiency will also require that domain specialist extend their skill to tools and formalism. That last point is a human factor that method cannot handle and shall be addressed by

The hardest part remains the coordination of specialists regarding their models implementation. The derivation of one model to another will foster this activity as less variability will be introduced by a specialist in its model. So this approach is compatible with gateway that some tool vendor propose to go from SE model to another specialty model like SA.



5 **PoC** activities

Different PoCs were done to assess method under constraints required in sections 2.2.1 and 2.2.2 of this document.

Each PoC, use the following domain models versions (see description and access of data from Section 2.5 from LIV-S085L02-007-V6, ISX-S2C-LIV-1037-V6).

SEmodel	SA model
V4.4.3	V4.4.3

The constraint **#id-b** induced many cases to assess, see Table 3. But using SA models indicated in Section 2.4 of LIV-S085L02-007-V6, ISX-S2C-LIV-1037-V6, reduces the exploration because SA tools does not accept neither partial definition nor zero or partial execution. This prohibits columns **#**Case-A, -B, -D, -E, F, (in black) of the following table. To improve coverage of the surviving columns, Two different **S** models were considered:

The first partially defined and not executable, POCA

• The second partially defined and fully executable, POCB

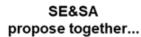
It shall be noticed that the semi execution can be reached by a combination of procedures fully executable suspended so that a non executable part of the execution is done mentally by the operator. That is why $\leq E=#Case-B$, SA=#Case-C> and $\leq E=#Case-E$, SA=#Case-C> (in grey) on the following table required the 2 features of PoC, but interrupted procedure has not lead to PoC contrarily to PoC A and PoC B. Snce SE model has not been fully implemented, cells $\leq E=#Case-A$, SA=#Case-C> and $\leq E=#Case-C$, SA=#Case-C> (in grey) on the following table are also discarded for a PoC.

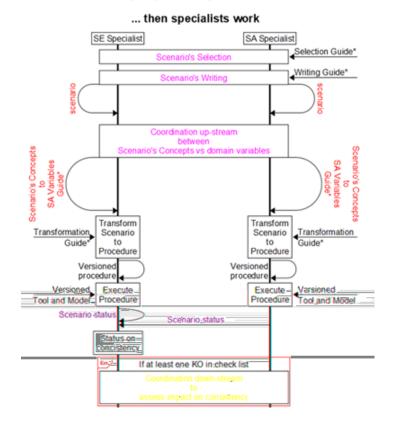
SE SA	#Case-A	#Case-B	#Case-C	#Case-D	#Case-E	#Case-F
#Case-A						
#Case-B						
#Case-C						
#Case-D			PoCA			
#Case-E						
#Case-F			PoCB			

Here above surviving cells have to be demuxed with the **#id-p** constraint. The worst case for each method is not to get advantage of previous method so **#sq-0** is only considered for each PoC.

As a reminder, the proposed approach for both PoCs is described below:







It must be noted that for the PoCA and PoCB presented in the following sections, neither auto nor alter validation activities have been performed on each activity represented in Figure 13.

Regarding the related artefacts, there was no Selection Guide, Writing Guide or transformation Guide, but PoCactivities were performed in an opportunistic way and very oriented to the End to End and the bipartite (between SE and SA) characterization of scenarios rather than formal handling of artefacts.

In order to choose the scenarios to be analyzed, from a SA point of view, some scenarios were selected regarding the minimal cut sets involved in the Failure Conditions assessment or sequences issued from MBSA. Other scenarios have ween SE and SA,

since it was



5.1 **Proof-of-concept**

5.1.1 **Preliminary input material**

In order to illustrate the proposed methods, we used the AIDA case study¹ developed by IRTS Exupery. As a starting point for the PoCs, IRT St-Exupery developed MBSE and MBSA models for this system. For more detail see LIV-S085L02-007-V6, ISX-S2C-LIV-1037-V6.

5.1.2 **PoCs overview**

Theses PoCs were established to assess benefit of Behavioral Cross Checked approach on a system whose complexity is representative of industrial systems. To perform this, it has been considered to use same use case and scenarios on 2 different MBSE models and capabilities:

PoC A

of models is performed by analysis

of the developed models.

PoC B: focuses on existing use case, and develop equivalent MBSE models in language that enables execution of the models (SYSML² language and associated execution semantics (fUML³, PSCS⁴, PSSM⁵)). The behavior is described in a way which enables execution and verification of information propagation during execution.

As both PoCs have been performed on the same system and use common artifacts, we have considered the following common steps and artifacts before performing specific activities for each PoC. The applied strategy is summarized in the figure below:

¹ AIDA :

case study developed by IRT St-Exupery proposes a system to assist Aircraft Pilot in the pre-flight checks operation. This system is composed of a ground station and an autonomous Unmanned Aircraft Vehicle. MBSE and MBSA models were developed by IRT & Exupery to illustrate S2C proposed methods.

² Standard System Modelling Language defined by Object Management Group. https://www.omgsysml.org/

³ Semantics of a Fundamental Subset for Executable UML Models https://www.omg.org/spec/FUML/

⁴ Precise Semantics of UML Composite Structures <u>https://www.omg.org/spec/PSCS/1.2/About-PSCS/</u>

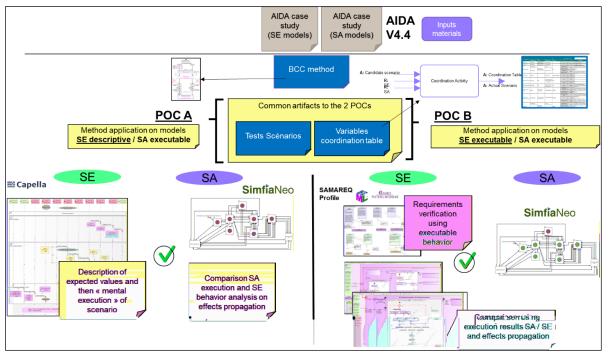
⁵ Precise Semantics of UML State Machines <u>https://www.omg.org/spec/PSSM/1.0/About-PSSM/</u>

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IRT Saint Exupéry LIV- S085L02-025 IRT SystemX ISX-S2C-DOC-438

Version: V6



5.1.3 Common activity 1– Scenario Initialization

This first activity (defined in Scenario initialization

) consisted of selecting, in agreement between both teams, appropriate scenarios for consistency analysis. For the AIDA case study, we decided to focus our effort on the following Scenarios:

(a) Scenario 1: Loss of motor

This scenario considers the loss of a motor during normal mission operation in Automatic Flight mode (the quadcopter follows a preconfigured flight plan). During the mission, a motor fails, then leads to unexpected trajectory control. The from fault detection to

reconfiguration (faulty motor power supply is shut down). The scenario also considers the pilot reaction after his detection of the unexpected trajectory => to take over the control of the quadcopter to land it with manual control.

(b) Scenario 2: Loss of Attitude Information

This scenario considers the situation when the UAV (Unmanned Aerial Vehicle) is in normal operation in Automatic Hight mode during which it is inspecting the aircraft (flight is in allowed area), and where a loss of attitude (pitch) information occurs. Attitude monitoring function will detect this loss and will shut off the power supply of all motors. The pilot will then detect this abnormal behavior and will take control back by switching to manual mode will not be able to do anything since the motors are not available. Eventually, the drone will crash inside the authorized area.

(c) Scenario 3: Position Information Erroneous



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This scenario considers the situation when the UAV is in normal operation in Automatic flight mode during which it is inspecting the aircraft (in flight in allowed area), the occurrence of erroneous position signal information (GPS signal noise), and the UAV will not follow the flight plan anymore. The pilot will detect the abnormal trajectory and will switch to manual mode, where he will stop the mission and will land the drone safely.

(d) Scenario 4: Switch From Auto to Manual Mode

This scenario considers the situation when the UAV is in normal operation in Automatic fight mode during which pilot requests to switch from Automatic mode to Manual mode through the remote control (Manual Override). Once he has taken the control, the pilot requests to land the UAV on the ground in an authorized area.

It may be noted that this scenario is not related to failure of the system. However, it is an interesting scenario since it corresponds to an operational situation that must be coherent between both models.



5.1.4 Common activity 2 - Upstream coordination between Scenario Concepts vs. Domain Variables

As a second step (defined in Upstream coordination between Scenario Concepts vs. Domain Variables), the method proposed to identify the variables to consider for consistency checks between SE and SA and also consider their relative validity domains for each selected scenario.

Here is an example of Coordination Table for Scenario 1:

Scenario Concept		SE	\$	5A	Value's domain correspondance		
Scenario Concept	¥ariable/observer SE	SE ¥alues	¥ariablełobserver SA	SA ¥alues	SE	SA	
Drone in flighy	Drone real position	XYZ position vector value included in specific shape	N/A: Voir commentaires				
Drone insied authorized area	Drone real position	XYZ position vector value included in specific shape	N/A: Voir commentaires			-	
			0 // 05400		AUTOMATIC Flight Plan		
Automatic Mode	Control Mode Internal	AUTOMATIC Flight Plan	Sortie SF4.3.2	AUTO	AUTOMATIC Speed Consign	AUTO	
	Control Mode Pilote	AUTOMATIC Speed Consign	EXT_PilotDetection.PilotS electedMode		MANUAL	MANUAL	
loss of motor	Motor s motion	0	SF1i2_CreateMotion	LOST (failure mode "fail loss")	0	LOST	
		·		Loor (randit mode rangioso)	!=0	OK / ERRONEOUS	
Motor loss detection	Motor x runaway	TRUE	SF7.SF3_MonitorParamet ers.SF734_MonitorDroneM	TRUE	TRUE	TRUE	
			otors.Motro1Runaway		FALSE	FALSE	
Shut off motor lost	Motor x disabled	TRUE	SF7.SF73.MonitorParamet ers.MotorsDisabled_Motor	TRUE	TRUE/FALSE	TRUE/FALSE	
	Global thrust		SF1.GlobalThrustAndTorque		=Required Thrust +/- acceptance margin	ОК	
Consequence motor		!= Required Thrust +/- acceptance margin		ERRONEOUS	0	LOST	
000		doceptance margin			!=Required Thrust +/- acceptance margin AND !=0	ERRONEOUS	
	Sensed drone position	XYZ position vector value à comparer avec flight plan	SF2.DetectControlDronePos ition		= flight plan +/- acceptance margin	ОК	
Pilot detection abnormal behavior				ERRONEOUS	0	LOST	
					!= flight plan +/- acceptance margin	ERRONEOUS	
	Control Mode Internal	ol Mode Internal		Sortie SF4.3.2		AUTO	
Manual Mode		MANUAL Flight Plan		MANUEL	AUTOMATIC Speed Consign	MANUEL	
	Control Mode Pilote	MANUAL Speed Consign	EXT_PilotDetection.PilotSele ctedMode		MANUAL Flight Plan		
					MANUAL Speed Consign	MANOLL	
and drawn control	Global thrust	!= Required Thrust +/-	251 Clobal Threat And Tarawa	ERRONEOUS	=Required Thrust +I- acceptance margin	ОК	
oss of drone control	Giodal thrust	acceptance margin	SF1.GlobalThrustAndTorque	ERRONEOUS	0 != Required Thrust +/-	LOST	
					acceptance margin AND != 0	ERRONEOUS	
			SF1.SF11_ControlHelix1.SF1i3_		=Required Propeller Thrust +/- acceptance margin	ОК	
Propeller off	Propeller x thrust	0	CreateThrustAndTorque.outp	LOST	0	LOST	
			ut		!= Required Propeller Thrust +/- acceptance margin AND !+0	ERRONEOUS	
Motor shutdown power	Motor Shutdown	TRUE	SF1.SF11_ControlHelix1.SF1i6_ DepowerMotor	TRUE	TRUE	TRUE	
			Depowermotor		FALSE	FALSE	

It can be noticed that in case the **SSR method** has been applied before, the variables consistency mapping can be extracted from C-LINK definition and speed up the process.

These variables may be identified according to expected observations (relevant elements to focus during execution of both models) in the \mathfrak{E} / SA models.

Finally, it can also noticed that identifying Variables Coordination Table (between SE and SA) might be difficult if equivalences/consistency between the 2 models is difficult to establish. The more similar the models are, the easier and more feasible will be this phase of upstream coordination.



5.1.5 Common activity 3 – Transformation from Scenario to Procedure

Then, after identifying the variables, it is the time to write the expected SE and SA verification procedures (as defined in Transformation from Scenario to Procedure

).

(a) Example of SE Verification procedure

The Verification Procedure is written using adhoctest template (inspired from personal experience). An example of Test procedure is provided below:

6. Test principle		
 Launch MBSE simulation environment Initialize scenario preconditions (start sc in the allowed area around the aircraft) Execute simulation step by step Observe variables and simulation results Stop the MBSE Simulation environment 		AV is starting inspection and is
7. Preconditions		
Drone is in flight in allowed area (drone real pos to follow an inspection plan. Drone is in AUTOMATIC mode All equipments behave normally – modes machi 8. Test procedure – steps	-	·
on until UAV is around the aircraft	Action:	Open MBSE tool and start standard simulati
		in the allowed area
ed area	Expectatio	Drone real position is included in the allow
	n:	Drone follows the flight plan
		Control Mode = AUTOMATIC
	Result:	



(b) Example of SA Verification procedure

For SA, the Verification Procedure is written adopting the standard Test procedure pattern from the SE. This is not a current SA practise to find such writing test activities. An example of Test procedure is provided below:

	I.→Test·proced	ure	
I			
	a.→AIDAV4	143.001-SA-001¶	
÷			_
	Action:¤	Look-for-function-"SF1i2_CreateMotion"-in-your-left-menu-and-trigger-	×
		its-failure-mode-"fail_loss"Double-click-on-"fail_loss"-failure-mode-	
		to-trigger-it-on-the-simulationFailure-modes-are-nested-under-the-	
		function-in-the- <i>Model-Explorer</i> -left-menu¤	
	Expected	Failure-mode-"fail_loss"-is-triggered-on-the-simulationThe-failure-	×
	results:¤	mode-once-is-triggered-it-should-have-disappeared-on-the-menuOn-	
0		the-layout, failed components are displayed in red colour. A	
Ð	Observed	"fail_loss" -failure-mode-does-not-appear-any-more-for-the-function-	×
	result:¤	"SF1i2_CreateMotion" Many- variables- have- changed- its- status- after-	
		$triggering \cdot the \cdot failure \cdot mode, \cdot some \cdot red \cdot colours \cdot are \cdot displayed \cdot in \cdot the \cdot main \cdot the \cdot mai$	
		view.·¤	
	Status:¤	OKx	¤
	Note (optional):	N/A¤	¤
	L ADA M	143.001-SA-002	
	D.→AIDAV4	143.001-SA-002	
		1-	٦.,
1	Action:¤	Check-for-observers-output-values-considered-in-this-test#	×
1	Action:¤ Expected·	Check-for-observers-output-values-considered-in-this-test¤ ↔ Motor 1-(failed-motor)-is-disabled: ¶	¤ ¤
1	Action:¤	Check for observers-output-values-considered-in-this-test¤ → Motor-1-(failed-motor)-is-disabled:-¶ SF7.SF73.MonitorParameters.MotorsDisabled_Motor1=-TRUE¶	-
	Action:¤ Expected·	Check for observers-output-values-considered-in-this-test¤ → Motor 1-(failed-motor)-is-disabled: ¶ SF7.SF73.MonitorParameters.MotorsDisabled_Motor1:=-TRUE¶ → Control-mode is-no-longer-AUTO, it-is-MANUAL-now: ¶	-
1	Action:¤ Expected·	Check for observers-output-values-considered-in-this-test¤ → Motor-1-(failed-motor)-is-disabled: ¶ SF7.SF73.MonitorParameters.MotorsDisabled_Motor1-=-TRUE¶ → Control-mode-is-no-longer-AUTO, it-is-MANUAL-now: ¶ EXT_PilotDetection.mode-=-AUTO¶	-
1	Action:¤ Expected·	Check for observers output-values considered in this test# → Motor 1 (failed motor) is disabled: ¶ SF7.SF73. MonitorParameters. MotorsDisabled_Motor1 = -TRUE¶ → Control-mode is no-longer.AUTO, it is MANUAL-now: ¶ EXT_PilotDetection.mode = AUTO¶ → Drone-loss-of-control-¶	¤
1	Action:¤ Expected·	Check for observers output values considered in this test#	¤
1	Action:¤ Expected·	Check-for-observers-output-values-considered-in-this-testx → Motor-1-(failed-motor)-is-disabled: ¶ SF7.SF73.MonitorParameters.MotorsDisabled_Motor1-=-TRUE¶ → Control-mode-is-no-longer-AUTO,-it-is-MANUAL-now:¶ EXT_PilotDetection.mode=:AUTO¶ → Drone-loss-of-control-¶ FC01_CAT_Uncontrolled_drone_crash_in_unauthorized_area- TRUE¶	я
1	Action:¤ Expected·	Check for observers output values considered in this test#	я
	Action:¤ Expected· results:¤	Checkfor-observers-output-values-considered-in-this-test¤ → Motor-1-(failed-motor)-is-disabled:-¶ SF7.SF73.MonitorParameters.MotorsDisabled_Motor1-=-TRUE¶ → Control-mode-is-no-longer-AUTO,-it-is-MANUAL-now:-¶ EXT_PilotDetection.mode==AUTO¶ → Drone-loss-of-control-¶ FC01_CAT_Uncontrolled_drone_crash_in_unauthorized_area-=-TRUE¶ FC02_HAZ_Uncontrolled_drone_crash_in_authorized_area-=-TRUE¶ ×	H
	Action:X Expected results:X Observed	Check for observers output-values considered in this test# → Motor 1: (failed-motor)-is disabled: ¶ SF7.SF73. MonitorParameters. MotorsDisabled_Motor1-=-TRUE¶ → Control-mode is-no-longer.AUTO, it is MANUAL-now: ¶ EXT_PilotDetection.mode=-AUTO¶ → Drone-loss of control-¶ FC01_CAT_Uncontrolled_drone_crash_in_unauthorized_area ==- TRUE¶ FC02_HAZ_Uncontrolled_drone_crash_in_authorized_area ==-TRUE¶ ¤ Following-results are-obtained: ¶	я
	Action:¤ Expected· results:¤	Check-for-observers-output-values-considered-in-this-test¤	H
1	Action:X Expected results:X Observed	Check-for-observers-output-values-considered-in-this-test¤ → Motor-1-(failed-motor)-is-disabled: ¶ SF7.SF73.MonitorParameters.MotorsDisabled_Motor1-=-TRUE¶ → Control-mode-is-no-longer-AUTO,-it-is-MANUAL-now: ¶ EXT_PilotDetection.mode=AUTO¶ → Drone-loss of-control-¶ FC01_CAT_Uncontrolled_drone_crash_in_unauthorized_area- TRUE¶ FC02_HAZ_Uncontrolled_drone_crash_in_authorized_area-=-TRUE¶ ¤ Following-results-are-obtained: ¶ SF7.SF73.MonitorParameters.MotorsDisabled_Motor1-=-TRUE¶ EXT_PilotDetection.mode=AUTO¶	H
1	Action:X Expected results:X Observed	Check-for-observers-output-values-considered-in-this-test¤	H
1	Action:X Expected results:X Observed	Check-for-observers-output-values-considered-in-this-testx → Motor-1-(failed-motor)-is-disabled: ¶ SF7.SF73.MonitorParameters.MotorsDisabled_Motor1-=-TRUE¶ → Control-mode-is-no-longer-AUTO,-it-is-MANUAL-now:¶ EXT_PilotDetection.mode=-AUTO¶ → Drone-loss-of-control-¶ FC01_CAT_Uncontrolled_drone_crash_in_unauthorized_area-=- TRUE¶ FC02_HAZ_Uncontrolled_drone_crash_in_authorized_area-=-TRUE¶ R Following-results-are-obtained: ¶ SF7.SF73.MonitorParameters.MotorsDisabled_Motor1-=-TRUE¶ EXT_PilotDetection.mode=-AUTO¶ FC01_CAT_Uncontrolled_drone_crash_in_unauthorized_area-=-	H H
	Action:X Expected results:X Observed	Check for observers output-values considered in this-testx → Motor 1 (failed-motor) is disabled: ¶ SF7.SF73. MonitorParameters. MotorsDisabled_Motor1 =-TRUE¶ → Control-mode is no-longer.AUTO, it is:MANUAL-now: ¶ EXT_PilotDetection.mode =-AUTO¶ → Drone-loss-of-control-¶ FC01_CAT_Uncontrolled_drone_crash_in_unauthorized_area-=-TRUE¶ FC02_HAZ_Uncontrolled_drone_crash_in_authorized_area-=-TRUE¶ R Following-results-are-obtained: ¶ SF7.SF73. MonitorParameters. MotorsDisabled_Motor1-=-TRUE¶ EXT_PilotDetection.mode =-AUTO¶ FC01_CAT_Uncontrolled_drone_crash_in_unauthorized_area-=- TRUE¶	H H

5.1.6 PoC A - PoC SE model with scenarios (not executable) and SA executable model

This Proof of Concept has considered existing SE models of the AIDA case study provided as open source under open source license at the following link:

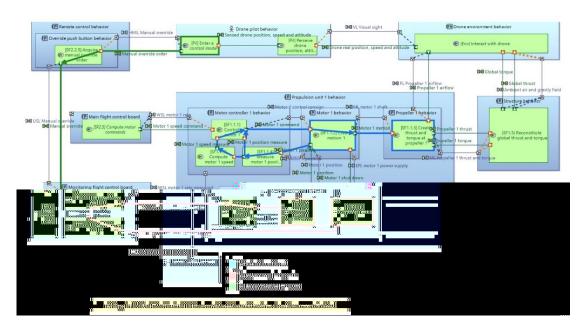
https://sahara.irt-saintexupery.com/AIDA/AIDAArchitecture/tags/AIDA_V4.4.



(a) Input Specialization

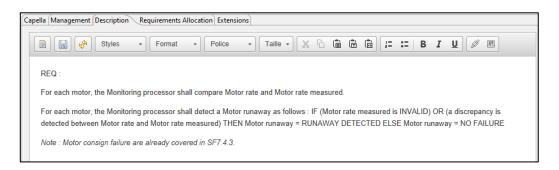
(i) SE Models:

This PoC focuses on the \mathfrak{E} #Case-D using mainly descriptive (as not exécutable) and non-fully implemented (as it does not covers all the facets of the system) for \mathfrak{E} using the Capella toolchain. These models contain the following elements:



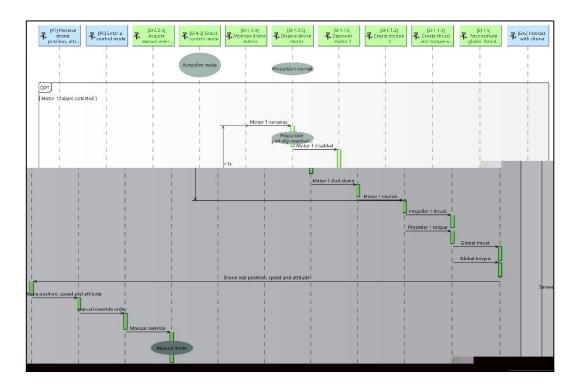
• Behaviors, Functions and associated Data Flows / Functional Chains:

o Behavior Textual Requirements for Functions regarding Validity evaluation:



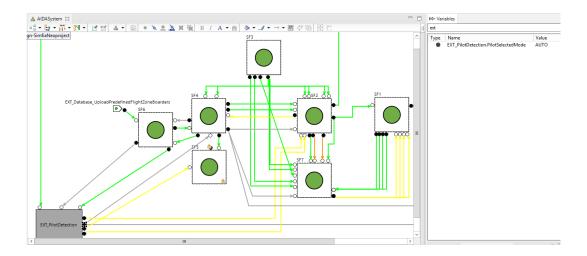


• Functional Exchanges Scenarios:



(ii) SA Models :

This PoCuses as SA models AltaRica based models developed with SmfiaNeo tool.



For these models, different scenarios driven by Failure Condition analysis were identified for the consistency analysis and are described in SE Models as *extended* Functional Scenarios. The SA model has not been modified to add any specific content specifically to perform this PoC.

From the list of Scenarios in section Scenario initialization

, there has only been one scenario that has been kept for the PoCs realization which is Scenario 1 Motor Loss The reason behind this choice is the amount of effort needed to perform the scenario decomposition in test artefacts and perform the method related activities. Since time and resources in the project were limited, only one scenario was performed.

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(b) PoC Results

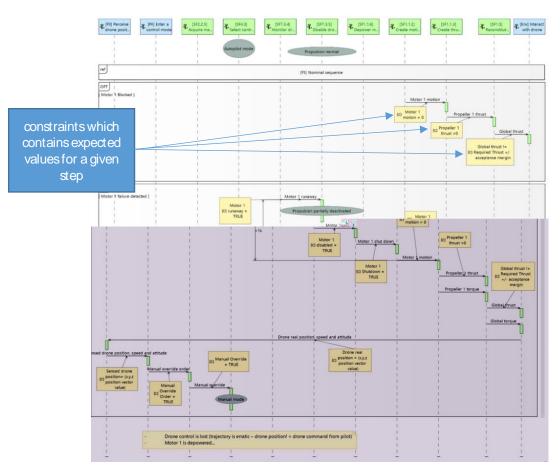
SE

For this PoC, after identifying the Coordination Variables Tables described in Common activity, the activity consisted in identifying for each step in the sequence, the expected variables values (test expected result for each test step).

(i)

<u>Scenario 1</u>: Motor Loss
The expected values ⁶

Scenarios:



(ii) SA

A step by step simulation has been performed in SmfiaNeo by introducing the failure modes on the respective components, in this case to simulate a Loss of motor.

AIDA-XX.YYY-SA-001

Action:	Open SmfiaNeo 1.3.2 and load model AIDA V4.4.3. Launch a and check initial conditions are as expected.	d
Expectation:	EXT_PilotDetection.PilotSelectedMode = AUTO	
Result:	EXT_PilotDetection.PilotSelectedMode = AUTO	

⁶ As Capella model cannot be executed, we have limited the added scenario diagram.

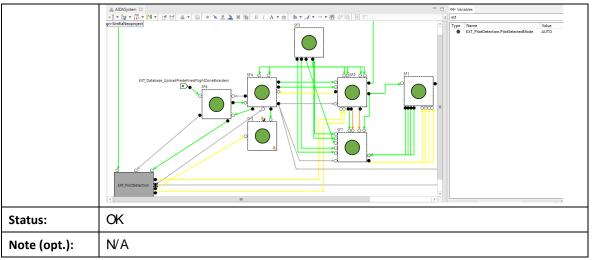
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AIDA-XX.YYY-SA-002

Action:	Check the thrust is equal to required thrust so that we can verify that all equipments are behaving normally.
Expectation:	SF1.GlobalThrustAndTorque = OK
Result:	SF1.GlobalThrustAndTorque = OK
Status:	OK
Note (opt.):	N/A

AIDA-XX.YYY-SA-003

Action:	SF1i2_CreateMotion in your left menu and trigger its failure mode
	fail_loss - fail_loss
	modes are nested under the function in the left menu.
Expectation:	
	The failure mode once is triggered it should have disappeared on the menu. On the layout, failed components are displayed in red colour.



Version: V6

Result:	🗲 Events (triggerable) 🕕 🖻
	type filter text
	AlDASystem
	EXT_Database_UploadPredefinedFlig
	_ Ź tail_loss
	SF1
	∡ SF1i1_ControlMotor
	🗲 fail_error 🗲 fail_loss
	✓ Tail_Joss
	▲ SF12_CreateMotion
	✓ fail_error
	₹ fail loss
	SF1i3_CreateThrustAndTorque
	🖉 fail_error
	🖌 fail_loss
	a 🔤 SF1i4_5_MeasurePositionAndR
	😽 fail error
	the failure mode, some red colours are displayed in the main view.
Status:	OK
Note (opt.l):	N/A

AIDA-XX.YYY-SA-004

Action:	Check thrust is not created anymore from the propeller whose motor is disabled.
Expectation:	SF1.SF11_ControlHelix1.SF1i3_CreateThrustAndTorque.output = LOST
Result:	SF1.SF11_ControlHelix1.SF1i3_CreateThrustAndTorque.output = LOST
Status:	OK
Note (opt.l):	N/A

AIDA-XX.YYY-SA-005

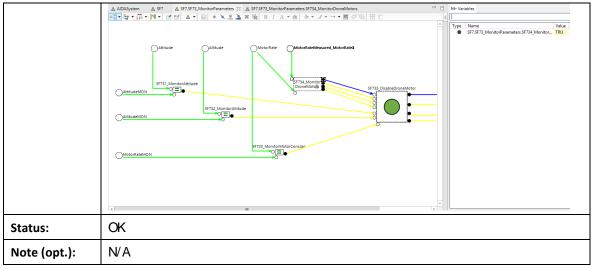
Action:	Due to loss of motor the global thrust will be less than required thrust.
Expectation:	SF1.GlobalThrustAndTorque = ERRONEOUS
Result:	SF1.GlobalThrustAndTorque = ERRONEOUS
Status:	OK
Note (opt.):	N/A

AIDA-XX.YYY-SA-006

Action:	The failure of motor will be detected, and propulsion will be partially deactivated in the later steps
Expectation:	SF7.SF3_MonitorParameters.SF734_MonitorDroneMotors.Motro1Runaway = TRUE
Result:	SF7.SF3_MonitorParameters.SF734_MonitorDroneMotors.Motro1Runaway = TRUE



Version: V6



AIDA-XX.YYY-SA-007

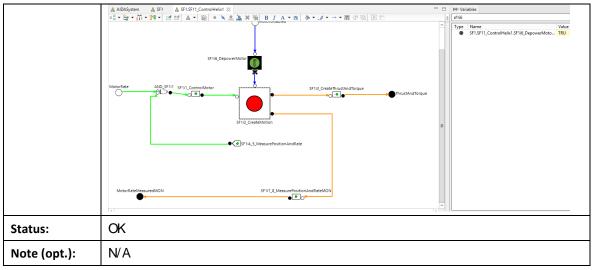
Action:	The failed motor will be disabled
Expectation:	SF7.SF73.MonitorParameters.MotorsDisabled_MotorX = TRUE
Result:	Str.Str3.MonitorParameters.MotorsDisabled_MotorX = TRUE
Status:	OK
Note (opt.):	N/A

AIDA-XX.YYY-SA-008

Action:	The disabled/motored motor is shutdown
Expectation:	SF1.SF11_ControlHelix1.SF1i6_DepowerMotor = TRUE
Result:	SF1.SF11_ControlHelix1.SF1i6_DepowerMotor = TRUE



Version: V6



AIDA-XX.YYY-SA-009

	SA		
Action:	The control mode is switched from Automatic mode to Manual mode		
Expectation:	EXT_PilotDetection.PilotSelectedMode = MANUAL		
Result:	EXT_PilotDetection.PilotSelectedMode = AUTO		
	ADAGSystem 23 		
Status:	КО		
Note (opt.):	Mode has not switched from AUTO to MANUAL as it was expected. After triggering the failure mode, the mode remains AUTO. However, FC01, FC02 and Motor Disabling function had the expected behaviour. After looking for the root cause of the anomaly, it has been found that change from AUTO to MANUA control mode, regarding failures of the propeller is only considered for the LOST and not the ERRONEOUS		

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(c) PoC Conclusion

During this PoC, the activity consisted to create verification procedures based on identified failures scenarios. This activity has to be performed when MBSE / MBSA models are created (early in the development process) but can be performed at latest to execute the tests on the real system.

This process seems to be compatible with existing activities. However, as behavior is not executed on the SE side, values and expected results consistency should be ensured by System Engineer himself and it could be very hard to identify inconsistencies in the expected results in the SE Model (as it focuses mainly on the sequences, data flows and not on the executable behavior).

5.1.7 PoC B - PoC executable SE model

(a) **PoC Specialization**

For this PoC, objective is to develop and assess benefits of using SE executable models. It must be noted that SA is identical in PoCA and PoCB (because SA is already developed as executable model).

In order to be able to compare objectively **PoC A** and **PoC B** results, we have decided to use the same case study based on AIDA V4.4 contents.

As Capella models do not propose (in its original core concepts) execution semantics, we have decided to model AIDA V4.4 with SYSML⁷ language and associated execution semantics (fUML⁸, PSCS⁹, PSSM¹⁰). Moreover, as SysML do not propose similar concepts proposed by Arcadia/Capella, we have created SysML model using a SE Method and SYSML profile based on Samares-Engineering internal knowledge described in Annex SAMAREQ Profile.

Finally, in order to assess compliance between Capella and SysML models, we have used the Review Consistency tool. These derived results are presented in **Annex** *Derived Result*.

Since time and resources in the project were limited, only one scenario was performed.

⁷ Standard System Modelling Language defined by Object Management Group. <u>https://www.omgsysml.org/</u>

⁸ Semantics of a Fundamental Subset for Executable UML Models <u>https://www.omg.org/spec/FUML/</u>

⁹ Precise Semantics of UML Composite Structures <u>https://www.omg.org/spec/PSCS/1.2/About-PSCS/</u>

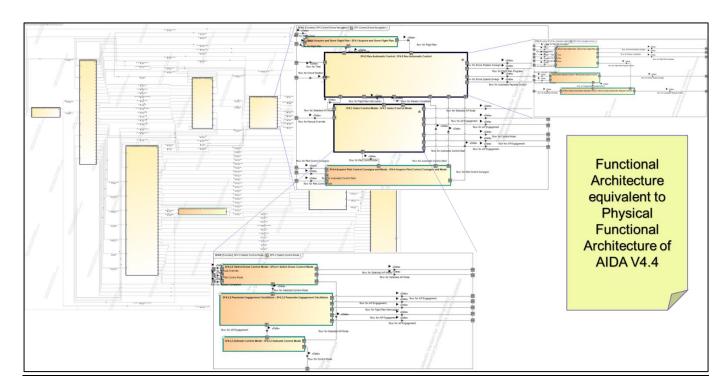
¹⁰ Precise Semantics of UML State Machines https://www.omg.org/spec/PSSM/1.0/About-PSSM/

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SysML model – Functional Architecture overview

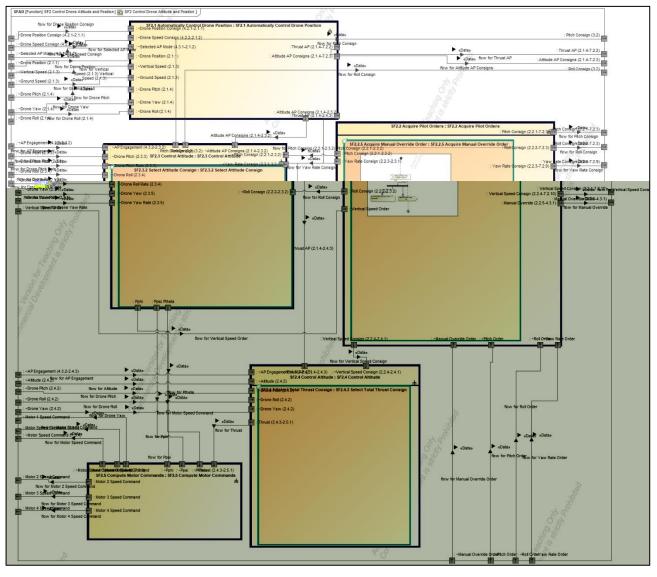


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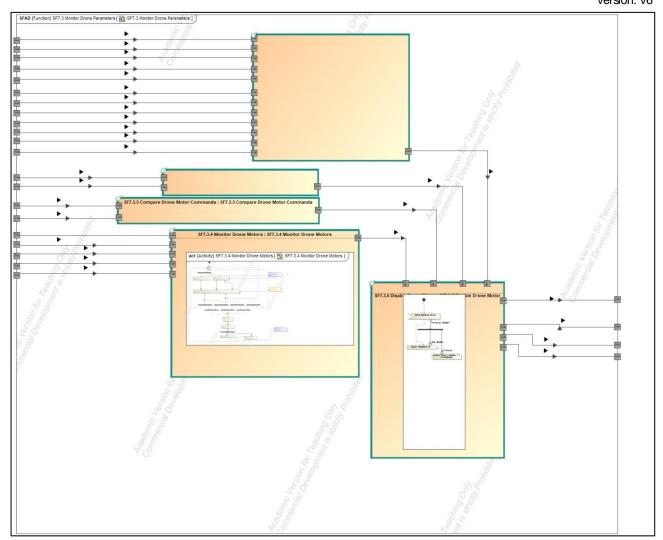
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In this functional architecture, we defined a model with similar hierarchical structure than the initial Capella model and variables names have been preserved. The SAMAREQ Profile distinguishes Composite Functions and their associated leaves. To enable information propagation over the structure, our approach proposes:

- Behavior associated to Leaf Function¹¹: We have considered that only leaves host behavior (not the parent functions). So, the execution of the end to end behavior will be executed from an external source and will be successively propagated over the successive functions involved in the considered scenario. For each leaf function involved in the considered scenarios, a behavioral model must be associated (e.g Activity Diagram, State Chart or Parametric Diagram), which expresses how the inputs will be used to generate outputs over execution time.
- Generalization of delegation mechanism: This means that each port of a leaf function shall be connected to its parent function, then connections are propagated from the source leaf function to the target leaf function.

¹¹ In Capella/Arcadia, it is required to allocate functions to behavior components. So, this assumption seems compliant with other MBSE method

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Interface and Data Flows Specification: To implement appropriate mechanisms to simulation propagation of data along the functional architecture, we have used the following SysML mechanisms:

SFA D [F	unction] SF3 Provide Drone Navigation Data [🔂 SF3 Provide Drone Navigation Data]	A P
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	flow for Posticiting Signalescence Posticity and Signal (3.2) weasured Person Signal (3.2)	

 Interface Block Type : Each_data exchanged over the architecture is defined by an Interface Block as illustrated below:

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Specification of Data Interfac Specify properties of the selecte		peofication table. Choose the Expert or All options from the Properties drop-down list to see more properties.		
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 <u>Port Definition</u>: Each port references Interface Type which specifies data types and How Properties exchanged as illustrated below:

🛒 Specification of Data Port <> [Read-Only] X			
Specification of Data Port prop Specify properties of the selected	vertices Data Port in the properties specification table. Choose the Expert or All options from the Properties drop-dow	In last to see more properties.	
Be C 2 Avage of the first of the fi			
	Multiplicity Interface Is ID Owning Template Parameter	(Unspecified)	

• <u>Item Flows:</u> illustration of the below:

veys some item flows from one output to a specific input. An between 2 ports) is proposed

X Specification of Connector <	X Specification of Connector <> [Read-Only]					
Specification of Item Flow The Item Flow contains a list of specific Item Flow properties.						
Connector [- SF3.1 Measure Pf	Item Flow			lø 8		
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SysML model – Behavioral overview

As Behavior definition may be time consuming, we concentrated our efforts in this PoC to describe required behavior to execute selected scenarios.

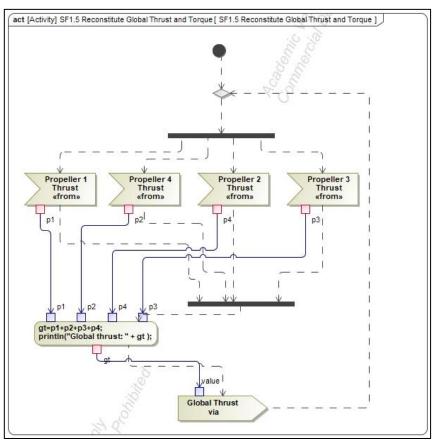
(ii). <u>Scenario 1</u> : Loss of a Motor

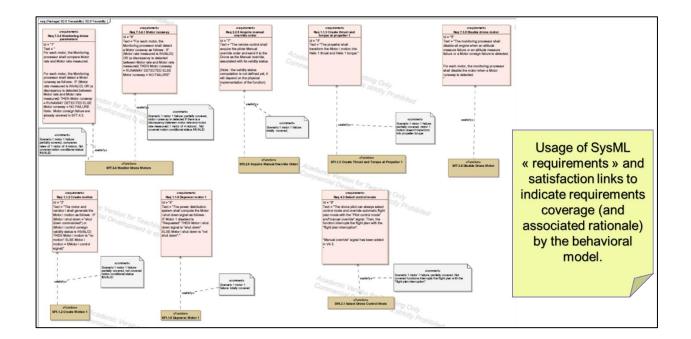
Firstly, we identified some specific functions which has effects on the overall modes (e.g. Control Mode of the AIDA System) which will be represented as a State Machine. The other functions are represented using SysML Activity Diagram concepts.

9.0		
P Selection	stm [State Machine] SF1.1.2 Create Motion 1 [SF1.1.2 Create Motion 1]	
Tools		
C State	8° 2°	Switch from normal
Composite •	normal mode	Switchholinionna
 Final State 	do / send speed motion	mode to failure mode
× Terminate	Motor 1 Shut Down	mode to randie mode
O Entry Point		
S Exit Point	Motor 1 Blocked	
Connection P		
Junction		
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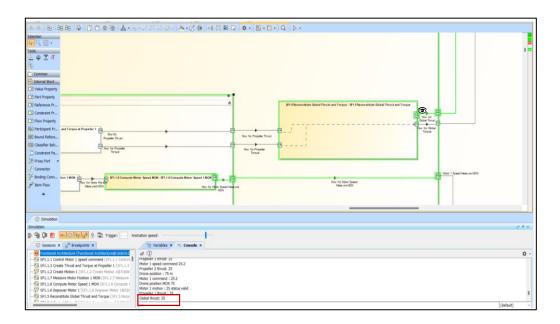
At execution start, we get on the HMI console the status and values of the MBSE variables which change over time:

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At runtime, the model is animated and it is possible to follow the propagation of variables and associated values over the MBSE architecture description:

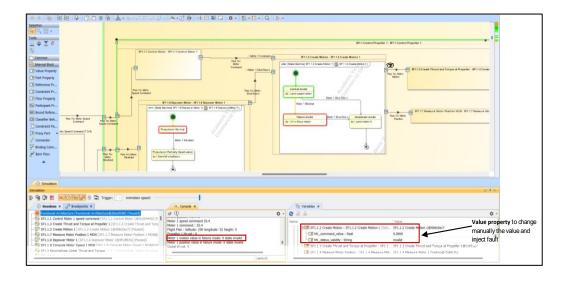


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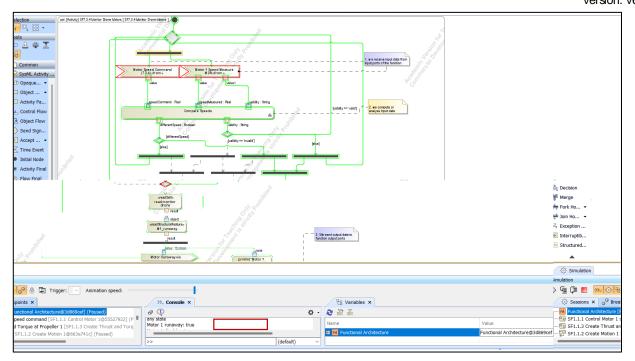
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B object Flow	
D Send Signal Action	
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Then, in order to inject fault in the model, we change an input value with the Cameo Smulation HMI:



Then, it is possible to observe propagation of the values over the architecture leading to the shutdown of the faulty motor:





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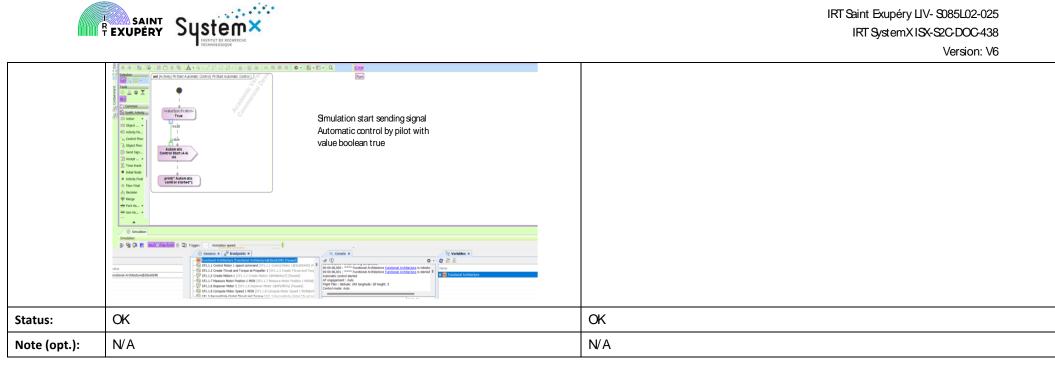
(b) **PoC Results**

(i)

AIDA-XX.YYY-SA-001

	SE	SA
Action:	Open MBSE tool and start standard simulation until UAV is around the aircraft in the allowed area	Open SmfiaNeo 1.3.2 and load model AIDA V4.4.3. Launch a and check initial conditions are as expected.
Expectation:	Drone real position is included in the allowed area	EXT_PilotDetection.PilotSelectedMode = AUTO
	Drone follows the flight plan	
	Control Mode = AUTOMATIC	
Result:		EXT_PilotDetection.PilotSelectedMode = AUTO
		ADDSystem (2) end of the first file of the firs

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(ii) AIDA-XX.YYY-SA-002

	SE	SA
Action:	The thrust should be equal to required thrust so that we can verify that all equipments are behaving normally.	Check the thrust is equal to required thrust so that we can verify that all equipments are behaving normally.
Expectation:	Global Thrust = Required thrust +/- acceptance margin	SF1.GlobalThrustAndTorque = OK
Result:		SF1.GlobalThrustAndTorque = OK

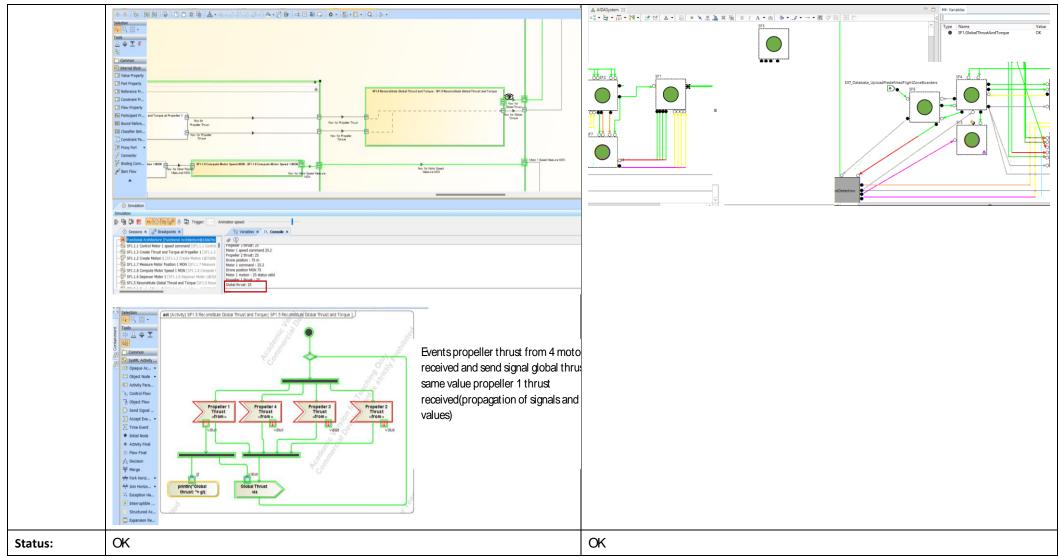




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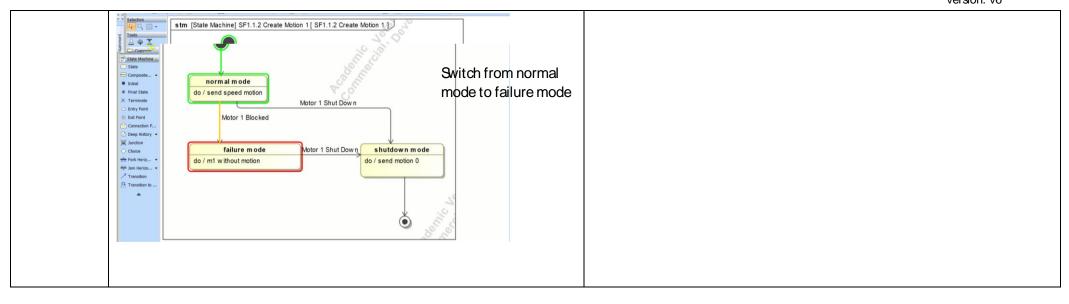


		Version: V6
Note (opt.):	N/A	N/A
(iii)	AIDA-XX.YYY-SA-003	
	SE	SA
Action:		SF1i2_CreateMotion in your left menu and trigger its failure fail_loss - fail_loss simulation. Failure modes are nested under the function in the left menu. Image: Simulation in the left
Expectation:	Motor x motion = 0	The failure mode once is triggered it should have disappeared on the menu. On the layout, failed components are displayed in red colour.
Result:	Image: Constrained on the constrained o	
		failure mode, some red colours are displayed in the main view.

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Status: OK OK		When event motor 1 command is read the function (read self), the value property, one to give value and the other to give status valid bouck in normal state. When value is changed to 0 or im the function inject the fault motor 1 command is read the function inject the fault motor 1 command is read the function inject the fault motor 1 command is and the other to give status valid bouck in normal state. When value is changed to 0 or im the function inject the fault motor 1 command is read the function inject the fault motor 1 command is and the other to give status valid bouck in normal state. When value is changed to 0 or im the function inject the fault motor 1 command is read the function inject the fault motor 1 command is and the other to give status valid bouck in normal to failure 1 with the function inject the fault motor 1 command is and the other to give status valid bouck in normal to failure 1 with the function inject the fault motor 1 command is and to chartly Fault motor 1 command is and the other to give status valid bouck in normal to failure 1 with the function inject the fault motor 1 command is and the other to give status valid bouck in normal to failure 1 with the function inject the fault motor 1 command is a state. When value is changed to 0 or im the function inject the fault motor 1 command is a state. When value is changed to 0 or im the function inject the fault motor 1 command is a state. When value is changed to 0 or im the fault motor 1 command is a state. When value is changed to 0 or im the fault motor 1 command is a state. When we	
	itatus:	OK	ОК

AIDA-XX.YYY-SA-004

(iv)

	SE	SA
Action:	The thrust will not be created from the propeller whose motor is disabled	Check thrust is not created anymore from the propeller whose motor is disabled.
Expectation:	Propeller x thrust = 0	SF1.SF11_ControlHelix1.SF1i3_CreateThrustAndTorque.output = LOST

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Result:	No. Bit Bit Control Propertier 1 Visit Propertier 1	
	Constant Constant	

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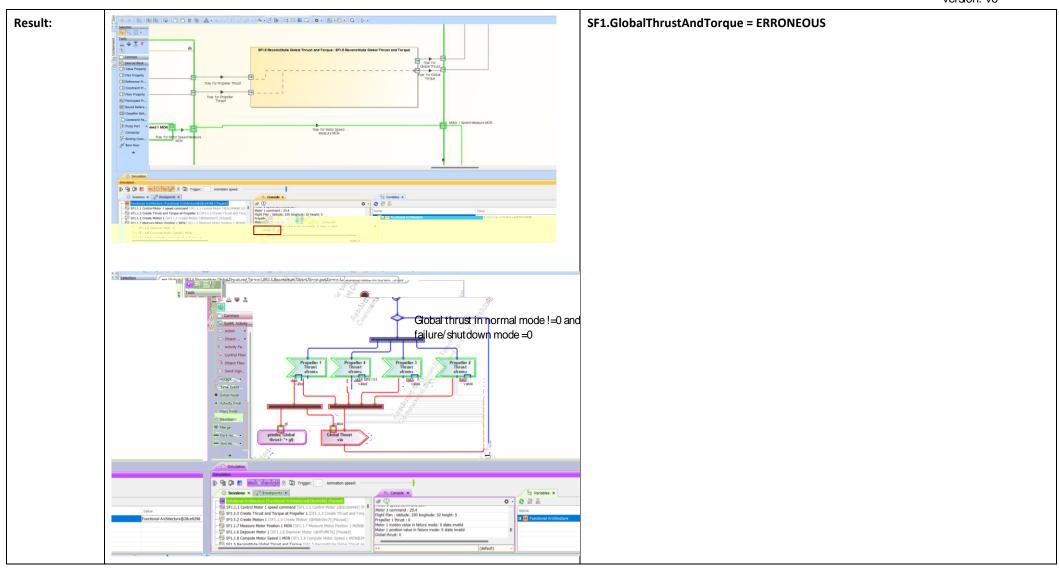
(v) AIDA-XX.YYY-SA-005

	SE	SA
Action:	Due to loss of motor the global thrust will be less than required thrust	Due to loss of motor the global thrust will be less than required thrust.
Expectation:	Global thrust! = Required Thrust +/- acceptance margin	SF1.GlobalThrustAndTorque = ERRONEOUS

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Version: V6

Status:	OK	OK
Note (opt.):	N/A	N/A

(vi)	AIDA-XX.YYY-SA-006	
	SE	SA
Action:	The failure of motor will be detected, and propulsion will be partially deactivated in the later steps	The failure of motor will be detected, and propulsion will be partially deactivated in the later steps
Expectation:	Motor x runaway = TRUE	SF7.SF3_MonitorParameters.SF734_MonitorDroneMotors.Motro1Runaway = TRUE
Result:	Interest Product UP 2 Addres One Mana [107 2 Addres One Mana] Interest Product UP	SF7.SF3_MonitorParameters.SF734_MonitorDroneMotors.Motro1Runaway = TRUE

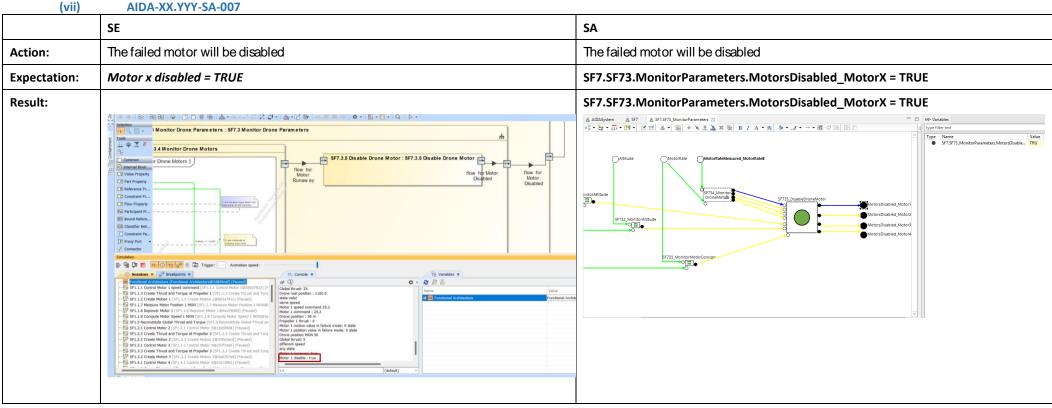
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Status:	OK	OK
Note (opt.):	N/A	N/A

AIDA-XX.YYY-SA-007



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		Version. vo
	Image: Control Flow Image: Control Flow Image: Control Flow Image: Control Flow <th></th>	
Status:	OK	OK
Note (opt.):	N/A	N/A

AIDA-XX.YYY-SA-008

(viii)

	SE	SA
Action:	The disabled/motored motor is shutdown	The disabled/motored motor is shutdown
Expectation:	Motor x Shutdown = TRUE	SF1.SF11_ControlHelix1.SF1i6_DepowerMotor = TRUE

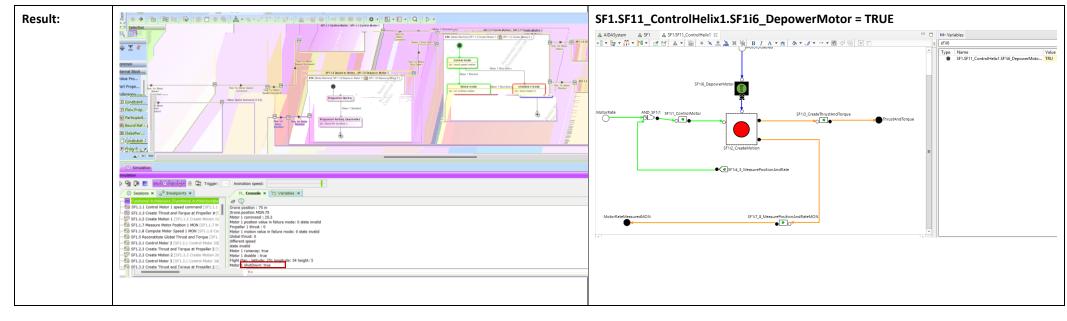
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IRT Saint Exupéry LIV- \$085L02-025 IRT SystemX ISX-\$2C-DOC-438

Version: V6

Stm [State Machine] SF1 16 Depower Motor 1] SF1 16	
Tools	
Image: State Propulsion Normal	
Chi Compe • Notor 1 Disabled	
• Initial	
Final State Propulsion Partially Deactivated	
X Terminate do / Send M1 shutDow n	
○ Entry Point	
© Deep H	
Sai Juncton	
♦ Choice	
🖶 Fork Ha	
🚧 Jon Ha 👻	
© Simulation	
Simulation	
🕼 🖳 📮 🗾 🐜 🚫 😵 🖉 Trigger: 🔹 Animation speed:	
♦ Sessions × 0 ^o Breakpoints ×	
- 🧖 Rectional Architecture [Functional Architecture]se d a 🗘 💭	
Propeller 1 thrust and Torque at Propeller 1 (Propeller 1 thrust : 0	
- DF SF1.1.2 Create Motion 1 [SF1.1.2 Create Motion 1] Motor 1 motion value in failure mode: 0 state invalid Global thrus: 0	
- CB SF11.7 Measure Motor Position 1 MOM (SF11.6 or Model SF1.2 M) different speed	
B SF1.5 Reconstitute Global Thrust and Torque [SF1. Motor 1 runaway: true	
Flight Plan: Lettrude: 251 longitude: 54 height: 5	
	1

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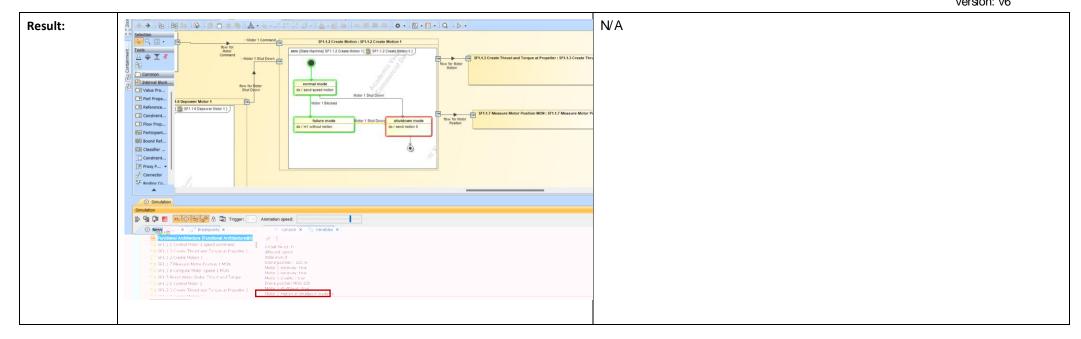
IRT Saint Exupéry LIV- \$285L02-025 IRT SystemX ISX-\$2C-DOC-438

Version: V6

(ix) AIDA-XX.YYY-SA-009

	SE	SA
Action:	The motion from motor which is in shutdown mode will be zero	N/A
Expectation:	Motor x motion = 0	N/A





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AIDA-XX.YYY-SA-010

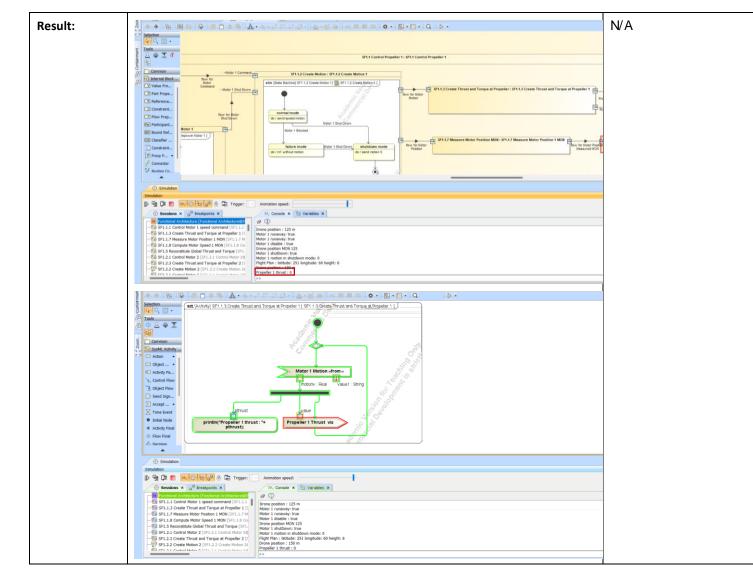
(x)

	SE	SA
Action:	The thrust will not be created from the propeller whose motor is in shutdown mode	N/A
Expectation:	Propeller x thrust = 0	N/A

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IRT SystemX ISX-S2C-DOC-438

Version: V6

Status:	OK	N/A
Note (opt.):	N/A	N/A

(xi)	AIDA-XX.YYY-SA-011	
	SE	SA
Action:	Due to loss of motor the global thrust will be less than required thrust and notify the pilot/operator of this	N/A
Expectation:	Global thrust! = Required Thrust +/- acceptance margin	N/A
Result:	We wanted in the second of	N/A
Status:	OK	N/A
Note (opt.):	N/A	N/A

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(xii) AIDA-XX.YYY-SA-012

Sensed drone position= (x,y,z position vector value)

Expectation:

Result:

	SE	SA	
Action:	Provide pilot the required parameters such as Drone real position, speed and attitude	N/A	
Expectation:	Drone real position = (x,y,z position vector value)	N/A	
Result:		N/A	
Status:	OK	N/A	
Note (opt.):	N/A	N/A	
(xiii)	(xiii) AIDA-XX-YYY-SA-013		
	SE	SA	
Action:	The pilot will understand/sense Drone position, speed and attitude	N/A	

N/A

N/A

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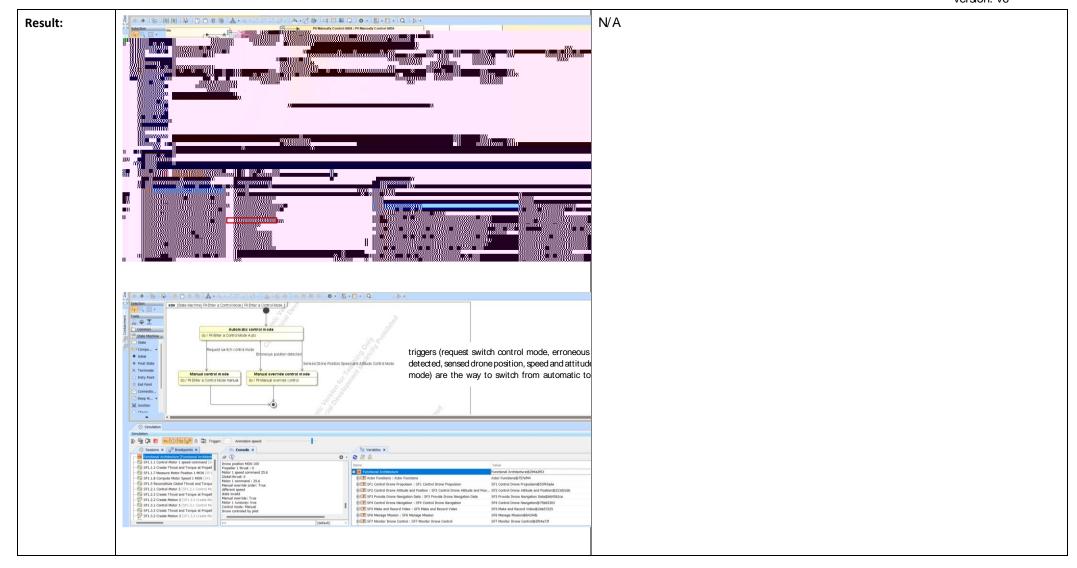


	Sensed and attitude control me Sensed and attitude control me Sensed in mitate the pilot's ability to perceive abnormal the drone. The other triggers are used in different scen	
Status:	OK	N/A
Note (opt.):	N/A	N/A

(xiv) AIDA-XX.YYY-SA-014

	SE	SA
Action:	Pilot will give the manual Override order	N/A
Expectation:	Manual Override Order = TRUE	N/A





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Version: V6

Status: OK N/A		Image: Second	
	Status:	OK	N/A

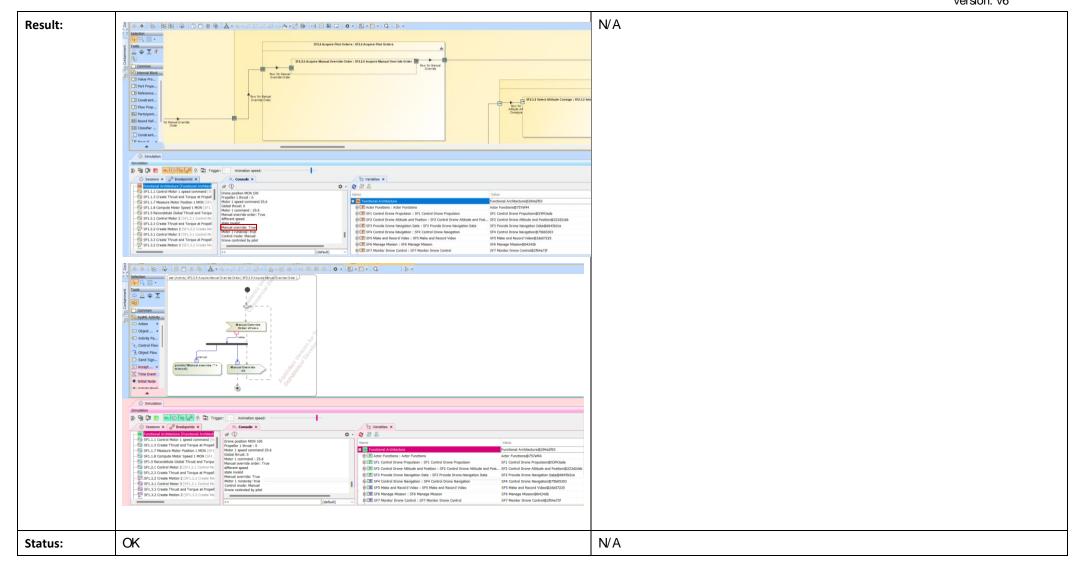
(xv) AIDA-XX.YYY-SA-015

	SE	SA
Action:	The manual override order will be executed	N/A
Expectation:	Manual Override = TRUE	N/A

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Version: V6

Note (opt.):	N/A	N/A
--------------	-----	-----

(xvi)	AIDA-XX.YYY-SA-016	
	SE	SA
Action:	The control mode is switched from Automatic mode to Manual mode	The control mode is switched from Automatic mode to Manual mode
Expectation:	Control mode = MANUAL	EXT_PilotDetection.PilotSelectedMode = MANUAL
Result:	Image: Section of Sectio	Ct

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	Constants Constants	
Status:	OK	КО
Note (opt.):	N/A	Mode has not switched from AUTO to MANUAL as it was expected. After triggering the failure mode, the mode remains AUTO. However, FO01, FO02 and Motor Disabling function had the expected behaviour.
		After looking for the root cause of the anomaly, it has been found that change from AUTO to MANUA control mode, regarding failures of the propeller is only considered for the LOST and not the ERRONEOUS

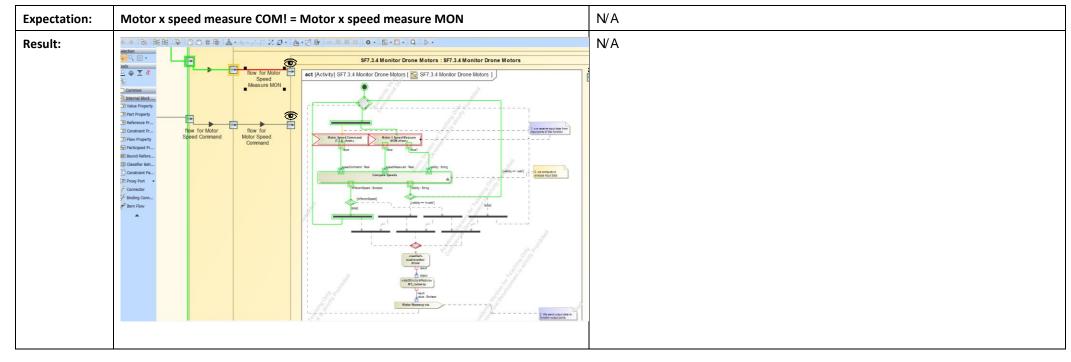
(xvii)	AIDA-XX.YYY-SA-xxx (optional)		
	SE	SA	
Action:	Detect the difference between the monitored and computed speed measure to verify the success of injection	N/A	

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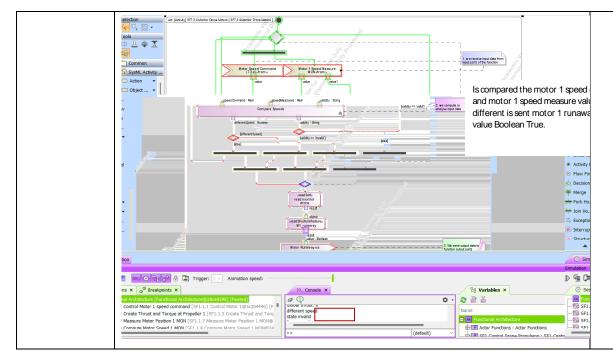
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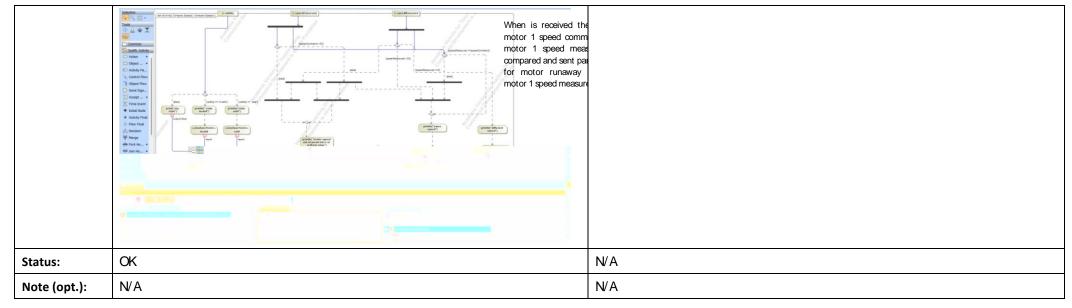


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(c) PoC Conclusion

During this PoC, the activity consisted in performing the same activities than in PoCA, but this time using an executable model for \mathfrak{E} and to observe the main differences with a non-executable \mathfrak{E} model. Given the results, it can be affirmed that \mathfrak{E} observations can be more easily contrasted with those from SA. An investment has been done to build the \mathfrak{E} model in an executable environment but if a considerable number of scenarios has to be executed and compared to SA, it is more interesting to have an executable model that will save up some time in the end and will be more accurate to read the results.

Inconsistencies are then easier to identify and more scenarios could be played in the same amount of time planned for performing the consistency activity between \mathfrak{E} and SA.

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6 Conclusion

It can be concluded that the BCC method improves the level of confidence on consistency. However it will also be subjective and relative for example to the selected scenarios, the validations done on each activity or the simulability level chosen. Full coverage is not accomplished, all possible tests on the models do not seem to be an achievable objective and selection of the scenarios to contrast becomes a critical activity of the method. Proof of concept results have shown that having both models that are fully simulable helps improving the method in terms of reciprocal understanding of each specialty (SE and SA), and consequently finding inconsistencies.

Regarding the effort required to perform this method, it seems not negligible and the risk to overcharge some key resources should be considered when performing this method. A significant number of artefacts must be created and maintained on versions to support the method as well. However, some activities or artefacts can be skipped but confidence level may be degraded accordingly.

To mitigate this statement, in Proof of Concept section, we have placed the focus on detailed functional architecture (down to physical architecture level) where a lot of artefacts should be developed to get a

of the physical system. Another approach (not explored in this PoCs) would have been to detail Behavioral execution of Functional Analysis at System Analysis (Regarding Needs analysis) where the consistency concentrates on behavior consistency with FHA instead of PSSA.

The method can be reused in some existing processes in the companies and can be subject to iteration processes once variations and impacts have been identified.

To sum up, each member must evaluate and plan the investment needed versus the gain the BCC method can provide in terms of confidence for their particular situation. As the method remains at an improvement of the level of confidence, future works could be to formally demonstrate the consistency.

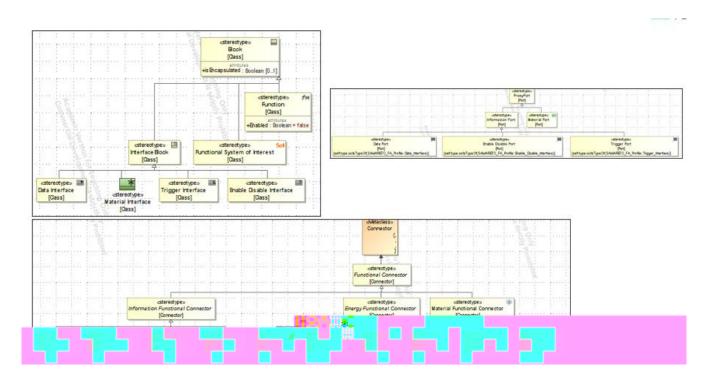


7 Appendixes

7.1 SAMAREQ Profile

The SAMAREQ Profile is a set of SysML Profiles and Diagrams Customization for Cameo Systems Modeller 19.0. It is provided under the Edipse Public Licence 2.0 and is available in a public gitlab repository at : https://gitlab.com/samareg-public/samareg-profile.

7.1.1 SAMAREQ Functional Architecture Profile

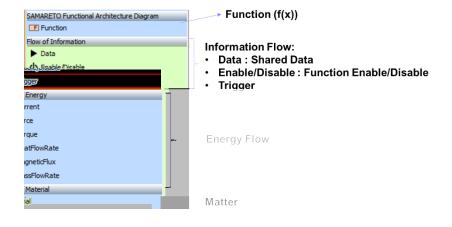


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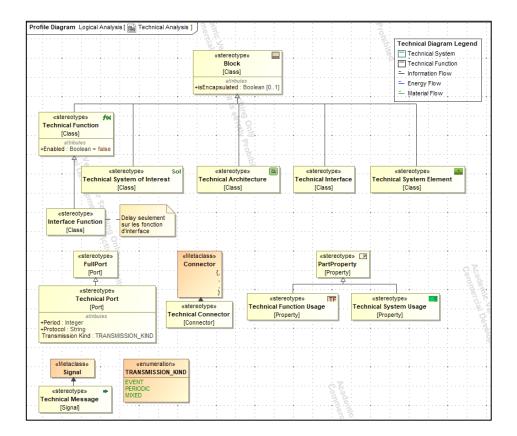
RESUPERY SUSTEMENT

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7.1.2 SAMAREQ Diagram Custoimization and Palette



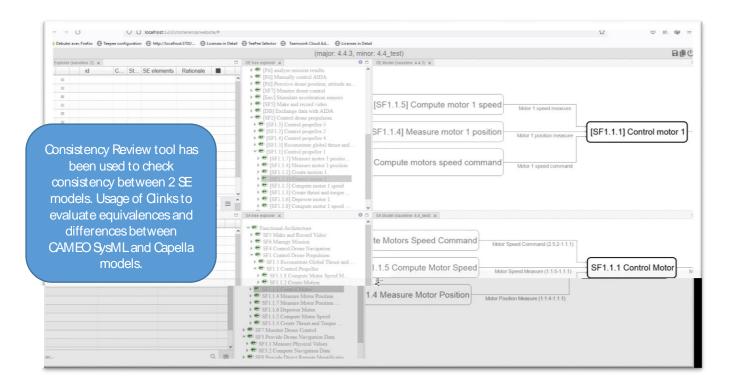
7.1.3 Logical Architecture Profile



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7.2 Derived Result : Consistency Check Capella Model and Cameo SysML Model



In order to assess equivalences between CAMEO SysML and Capella models, we have used the consistency support tool and assess functions equivalences (naming, inputs / outputs relations) between the 2 Capella and SysML model. This usage has allowed to quicky assess the equivalences between the 2 models.

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