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Title: Substantiated List of Suitable Monitors

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Summary: This Technical Note provides a list of suitable Independent Monitor Functions. The evaluation approach is described and the evaluation results regarding monitor effectiveness, robustness and required implementation effort is summarized. This Technical Note represents the deliverable D-6.2 of the “Horizon Europe Project: Flight Control Laws and Air Data Monitors” Lot 1 (EASA.2021.HVP.28)” project.

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Contents

Abbreviations

Acronym	Description
A/C	Aircraft
C	Source Code Manipulation
CAT	Catastrophic Flight Condition
CG	Centre of Gravity
DL	Direct Law
FAR	False Alarm Rate
FCF	Flight Control Function
FCL	Flight Control Laws
FMRA	Fachgebiet Flugmechanik, Flugregelung und Aeroelastizität, TU Berlin
FSEnv	Flight Simulation Environment
HAZ	Hazardous Flight Condition
HIR	Hit Rate
LOG	Flight Control Law Logics
IMF	Independent Monitor Function
NL	Normal Law
PFA	Probability of False Alarms
POD	Probability of Detection
PRT	Protection Function
SG	Signal Generator
SW	Software
THS	Trimmable Horizontal Stabilizer
TP	Trim Point
TS	Test Scenario

Definitions

Term	Definition/Meaning
Failure	A loss of function or a malfunction of a system or a part thereof. (ARP4761).
Active Failure	Failures where FCL function acts erroneously and independent from the input signals and cannot be influenced e.g., by the pilot commands. However, the outcome of the failure may vary in amplitude or its time response depending on the input signals. One typical signature of failures of this class is a runaway, which is an actuator-like failure [1].
Reactive Failure	Failures where FCL function reacts erroneously on inputs and is highly dependent on at least one input signal e.g. a command of the flight crew or from the measured signals of the flight condition itself. This class includes failures that increase the A/C's PIO tendency, reduce the damping of flight dynamic modes or deteriorate the A/C's handling qualities in other ways [1].
Failure Condition	The effect on the aircraft and its occupants both direct and consequential caused or contributed to by one or more failures, considering relevant adverse operational and environmental conditions. A failure condition is classified according to the severity of its effects as defined in advisory material issued by the certification authority (DO-178C Annex B).
Trim Point	An initial aircraft state which contains calculated dynamic aircraft parameters for desired flight envelope point. The trim routine and trim conditions are described in [2]
Test Scenario	Test Scenario comprises test inputs during simulation execution. It includes pilot inputs and initiation of FCL failures. A test scenario is a MATLAB script that specifies required deviations from the default test scenario.
Test Program	Generic term that includes all activities for testing to evaluate the monitor effectiveness and robustness.
False Positive	The FCL-Monitor triggers a false alarm during failure-free operation. This criterion is used for effectiveness tests and robustness tests.
False Negative	The FCL-Monitor does not detect a failure caused by a FCL development error. This criterion is used for effectiveness tests.
True Positive	The FCL-Monitor detects a failure caused by a FCL development error. This criterion is used for effectiveness tests.
True Negative	The FCL-Monitor does not trigger an alarm during failure-free operation. This criterion is used for robustness tests.

Symbols

Symbol	Meaning
α	Angle of attack
α_{max}	Maximum angle of attack
β	Sideslip angle
θ	Pitch angle
Φ	Roll angle
η_F	Flap deflection angle
n_z	Normal load factor
n_y	Lateral load factor
H	Altitude
H_{msl}	Height above mean sea level
m	Mass
N_E	Total number of Effectiveness Simulations
N_R	Total number of Robustness Simulations
N_{TP}	Number of True Positive Simulations
N_{FP}	Number of False Positive Simulations
N_{FN}	Number of False Negative Simulations
N_{TN}	Number of True Negative Simulations
t_f	Point of time when failure occurs
t_r	Latest monitor reaction time
t_g	Time when A/C is recoverable with a significant increase in pilot workload
V_{CAS}	Calibrated airspeed
V_{TAS}	True Air Speed
$V_{FCL,min}$	FCL low speed protection boundary
$V_{FCL,max}$	FCL maximum speed protection boundary
V_{FE}	Maximum flap extended speed
V_w	Wind speed
V_{MO}	Maximum operation speed
V_{NE}	Never exceed speed
V_D	Dive speed
V_S	Stall speed
Ma	Mach number

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[4] B. Laabs, „User Manual for the VFW614-ATD Flight Simulation Environment,“ TU Berlin, Berlin, 2023.

[5] B.Laabs, „Validation of the VFW614-ATD Flight Simulation Environment,“ Berlin, 2023.

[6] D. Hübener, „Evaluation Results of the Effectiveness Tests,“ Berlin, 2024.

[7] D. Hübener, „Evaluation Results of the Robustness Tests,“ Berlin, 2024.

[8] G. Weber, „Assessment of Required Effort for Implementation,“ Lindenberg, 2024.

Typographical Conventions

Following typographical conventions are used in this document:

Item	Convention to use	Example
Example Code	`Monospace Consolas` font	`A=5`
Folder name	*Arial* font, italics	*folder*
File name	***Arial*** font, bold, italics	***filename***
New terms	*Arial* font, italics	*Test Case*
variable	`Monospace Consolas` font	`variable`
bus signal	<u>`Monospace Consolas`</u> font, underlined	<u>`bus signal`</u>

1 Introduction

The Horizon Europe Project: "Flight Control Laws and Air Data Monitors" Lot 1 (EASA.2021.HVP.28) investigates the viability of an *Independent Monitor* for Flight Control Law Software (FCL SW) to detect FCL failures [3]. This Technical Note is a part of the delivery D-6.2 of the "EASA Horizon Flight Control Law Monitors". In Task 6, a qualitative assessment of the proposed Independent Monitor Functions (IMFs) is performed in respect to the required efforts and constraints for their implementation, and the most suitable IMFs are identified taking into account the trade-offs between performance and the required effort for their implementation.

TU Berlin uses the FCL SW that was developed in the VFW614-ATD technology project, in which new technologies for an Electronic Flight Control System were developed and demonstrated. The FCL SW and the desktop Flight Simulation Environment (FSEnv) of the VFW614-ATD flight dynamics are representative for a modern Fly-by-Wire (FbW) aircraft (A/C). This desktop flight simulation was prepared in Task 1 of the EASA.2021.HVP.28 project and extended by failure injection means. The documentation comprises a user manual [4], a programmer's guide [2] and a validation report [5].

This document identifies the most suitable IMFs based on the results described in references [6], [7] and [8]. It comprises the evaluation approach, a summary of previous evaluation results and a list of suitable IMFs.

1.1 Motivation

The objective of the Independent Monitor is to increase the safety of the FCS while maintaining highest rates of availability. It needs to be designed with thresholds and confirmation times set not so high as to not trigger when needed (effectiveness), and not so low as to lead to false alarms during failure-free operations (robustness).

The evaluation of the simulation results and implementation effort allows an identification of the most promising IMFs.

For future commercial development and certification purposes, a more extensive analysis over the complete flight envelope (e.g., with help of Monte Carlo simulations) might be required. This is out of scope in this project.

1.2 Report Structure

The report is structured as follows:

- Section 2 describes the approach for overall evaluation of IMFs based on the simulation results and implementation effort. The evaluation criteria is described, and a score system is defined.
- Section 3 summarizes the evaluation results regarding effectiveness, robustness and required implementation effort of the proposed IMFs.
- Section 4 summarizes the overall results. And a list of suitable independent monitor functions is provided.

2 Approach

Based on the evaluation results, the most suitable Independent Monitor Functions (IMFs) are identified taking into account the trade-offs between performances and the required efforts for their implementation. The desktop Flight Simulation Environment (FSEnv) is used to evaluate the effectiveness and robustness of the IMFs. Effectiveness refers to the ability of the IMF to detect the effects of FCL development errors before they lead to catastrophic (CAT) failure conditions. An IMF is considered robust if it does not trigger false alarms under failure free conditions. The simulation results are analysed and evaluated in references [6] and [7].

Additionally, a qualitative assessment of the proposed IMFs is performed in respect to the required efforts and constraints for their implementation and their maintenance in the context of large transport aircraft operations. The assessment of implementation effort is described in reference [8].

The three evaluation criteria (robustness, effectiveness and implementation effort) are used to identify suitable IMFs. Each criterion has a different weighting in the evaluation of suitable IMFs. The robustness is the most important criterion and has a weighting of 60 %. The effectiveness of IMFs is the criterion with the second highest weighting of 30 %. The weighting of the implementation effort is 10 %.

The results of the evaluation criteria can be divided into three groups: *good, acceptable* and *bad*. Points are awarded according to on the result class of each evaluation criterion. Where 100 is the maximum possible score and 11 the minimum possible score. Table 2-1 shows the points awarded for the results of the different evaluation criteria.

Table 2-1: Points awarded for results of evaluation criteria.

Result\Criterion	Robustness	Effectiveness	Implementation Effort	Total Score
good	**60**	**30**	**10**	**100**
acceptable	**30**	**20**	**5**	**55**
bad	**0**	**10**	**1**	**11**

The results for robustness evaluation are described in reference [7]. IMFs with a probability of false alarm[1] of less than $10^{-7}/fh$ are considered robust (*good*). IMFs that show a probability of false alarm greater than $10^{-5}/fh$ are not considered robust (*bad*). Everything in between is considered *acceptable*[2].

The results for effectiveness evaluation are described in reference [6]. IMFs that have contributed the most to the overall percentage of detection (POD) of the Independent Monitor of Flight Control Laws (see fifth column of Table 3-1 in reference [6]) **and** that allow recoverability, are considered effective (*good*). Recoverability means that the POD and RECy[3] of the IMF are similar for most of the relevant failures. IMFs that have contributed the most to the overall percentage of detection (POD) of the Independent Monitor of Flight Control Laws but **do not** allow recoverability in most cases are classified as *acceptable*. All other IMFs are classified as not very effective (*bad*).

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[1] The probability rates for triggering a false alarm are related to probability rates for external events, like gust or wind shear.

[2] It is recognised that any false alarm during the operation of an aircraft, regardless of its probability, is unacceptable. However, the objective of this project is to evaluate the general feasibility of concepts for Independent Monitoring of Flight Control Laws. Therefore, somewhat relaxed criteria for “acceptable” and “good” IMF robustness were defined. Considering the limited time and small team, the approach and the preliminary required false alarm probabilities to assess robustness are considered valid. See reference [7] for a detailed explanation.

[3] RECy is equivalent to POD. However, only failure detections that allow recoverability are considered as True Positives [6].

It is important to note, that the POD is highly dependent on the selected test conditions. Therefore, an IMF that showed *bad* effectiveness is award with 10 points as it may be more effective under different test conditions.

The implementation effort is assessed in reference [8]. A low implementation effort, when compared to the other IMFs is classified as *good*. A high implementation effort when compared to the other IMFs is classified as *bad*. Everything in between is considered *acceptable*.

It is important to note, that several of the proposed IMFs did not achieve the minimum goal for acceptable robustness. However, in most cases small changes in the thresholds or designs of the IMFs would result in an acceptable robustness. In these cases, the robustness of the IMF is classified as *acceptable*. To account for the trade-off between robustness and effectiveness, the result class for the effectiveness and implementation effort is changed to the next worst class, e.g. from *good* to *acceptable*. This is highlighted on the total score with the symbol †.

The evaluation of the individual IMFs is based on their overall score and involves four categories:

- highly recommended ($85 \leq total\ score$),
- recommended ($55 \leq total\ score < 85$),
- requires effort ($41 \leq total\ score < 55$), and
- not recommended ($total\ score < 41$).

IMFs with a score below 41 cannot be recommended. This includes all IMFs that are not robust. IMFs with scores between 41 and 55 show acceptable robustness, low to acceptable effectiveness and a high implementation effort. These IMFs have not shown good results but may have potential if a significant development effort is invested. A total score between 55 and 85 points includes IMFs that showed acceptable robustness, effectiveness, and implementation effort, or good robustness and acceptable effectiveness combined with a high implementation effort. These IMFs can be recommended. At last, all IMFs with a total score of above 85 points are highly recommended. They have good robustness and at least acceptable effectiveness and implementation effort.

3 Substantiated List of Suitable Monitors

The Independent Monitor of Flight Control Laws (IM-FCL) should effectively detect failures that lead to a catastrophic failure condition while being robust against false alarms in failure free conditions. Over two-thousand test conditions were defined and simulated in the FSEnv to evaluate the effectiveness and robustness of the proposed Independent Monitoring Functions (IMFs). The test conditions include external disturbances, or failures that result in an exceedance of at least one (safe) flight envelope limit or in reduced manoeuvrability of the aircraft.

It is important to note that the results of the robustness and effectiveness evaluations described in references [6] and [7] are highly dependent on the selected test conditions. The authors acknowledge that the investigated test conditions do not cover all possible failures nor all possible external disturbances. Therefore, the results presented in the following text are only valid for the test conditions investigated.

Table 3-1 shows the condensed evaluation results of the twenty-four proposed IMFs, ranked from best to worst. The second column lists all IMFs. The first column shows the overall assessment of the IMFs based on their scores. The total score is given in the last column. Columns three to five contain the summarised results of the evaluation criteria (robustness, effectiveness and implementation effort).

Several of the proposed IMFs did not achieve the minimum goal for acceptable robustness. However, in most cases small changes in the thresholds or designs of the IMFs would result in an acceptable robustness [7]. In these cases, the robustness of the IMF is classified as *acceptable**. To account for the trade-off between robustness and effectiveness, the total score is calculated using the next worst class of the effectiveness and implementation effort. This is highlighted on the total score with the symbol †.

All limit check IMFs are classified as *recommended* or *highly recommended.* The five IMFs can detect failures that lead to extreme aircraft attitudes and exceedance of the safe flight envelope limits. However, recoverability is not always possible when relying on the Bank Angle, Normal Load Factor and Overspeed Limit Checks. Also, the Pitch Angle Limit Check can replace the Overspeed, Normal Load Factor and Angle of Attack Limit Checks without reducing the effectiveness of the IM-FCL. However, this may not be the case for other failure conditions.

The limit check IMFs are robust under the simulated test conditions. An exception is the Angle of Attack Limit Check. This IMF requires higher thresholds and larger confirmation times to achieve an acceptable level of robustness. Also, it has to be investigated whether the Bank Angle Limit Check is robust against wake vortex encounters. Overall, the simple design of limit check IMFs avoids adding new complexity and keeps the implementation effort low compared to other IMFs. This, combined with the good robustness and effectiveness results, leads to a classification of at least *recommended*.

Failures that lead to a reduced manoeuvrability of the aircraft are not detected by the limit check IMFs. This type of failures are best detected by the controllability check IMFs, which monitor whether the aircraft reaction is sufficient to allow normal manoeuvres. The POD of the Flight Path Controllability Check was below expectations because the pilot model did not generate large pitch commands that activate the IMF. It is assumed, that a pilot would increase the side stick pitch inputs, if no aircraft reaction is visible. This would activate the IMF and eventually trigger an alarm. Therefore, the effectiveness result was upgraded from *acceptable* to *good**. It has to be investigated if the Flight Path Controllability Check can be extended to detect a reduced pitch up authority or if a different IMF is required. Overall, the controllability check IMFs showed a good effectiveness and acceptable robustness. However, their implementation effort is higher when compared to the limit check IMFs. Controllability check IMFs are classified as *recommended*.

Also, the comparator check IMFs and the Pitch Trim Drift Check can detect failures that reduce the manoeuvrability of the aircraft. The Pitch Trim Drift Check monitors whether the elevator and THS commands are consistent with each other. This IMF detects failures that lead to out of trim conditions. It showed good effectiveness and acceptable robustness. The Pitch Trim Drift Check is classified as *recommended*.

The comparator check IMFs monitor the difference between the normal mode and direct mode FCL commands. A failure is detected when the command difference exceeds the monitoring threshold. Command runaway like failures are best detected by these IMFs, which have proven to have high effectiveness. However, their robustness needs to be improved. Also, the constraining condition of these IMFs is that the aircraft is operated in the normal flight envelope. The risk of a command runaway like failure manifesting itself in the normal flight envelope is lower than at the corners of the flight envelope.

Table 3-1: Condensed Evaluation Results.

Evaluation result	IMF	Robustness	Effectiveness	Effort	Total score
Highly Recommended	Pitch Angle Limit Check	**good**	**good**	**good**	**100**
	Bank Angle Limit Check	**good**	**accept.**	**good**	**90**
	Overspeed Limit Check	**good**	**accept.**	**good**	**90**
	Bank Angle Hands-free Check	**good**	**accept.**	**accept.**	**85**
Recommended	Overspeed Prot. Check	**good**	**bad**	**bad**	**71**
	Bank Angle Prot. Check	**good**	**bad**	**bad**	**71**
	Pitch Trim Drift Check	**accept.**	**good**	**accept.**	**65**
	Roll Rate Contr. Check	**accept.**	**good**	**accept.**	**65**
	Flight Path Contr. Check	**accept.***	**good***	**accept.**	**61†**
	Load Factor Limit Check	**accept.**	**accept.**	**good**	**60**
	Angle of Attack Limit Check	**accept.***	**good**	**good**	**55†**
Requires effort	Elevator Com. Comparison	**accept.***	**good**	**accept.**	**51†**
	Rudder Com. Comparison	**accept.***	**good**	**accept.**	**51†**
	Aileron Com. Comparison	**accept.***	**good**	**accept.**	**51†**
	Angle of Attack Prot. Check	**accept.***	**good**	**bad**	**51†**
	Roll Rate Hands-free Check	**accept.***	**good**	**accept.**	**51†**
	Sideslip Angle Hands-free check	**accept.***	**good**	**accept.**	**51†**
	Lat. Load Factor Hands-free check	**accept.***	**good**	**accept.**	**51†**
	Pitch Rate Sign Check	**accept.***	**good**	**accept.**	**51†**

Evaluation result	IMF	Robustness	Effectiveness	Effort	Total score
Requires effort	Roll Rate Sign Check	**accept.***	**bad**	**accept.**	**41 †**
	Load Factor Sign Check	**accept.***	**bad**	**accept.**	**41 †**
	Pitch Angle Prot. check	**accept.***	**bad**	**bad**	**41 †**
	Load Factor Hands-free check	**accept.***	**bad**	**accept.**	**41 †**
Not recommended	Aileron Com. Sign Check	**bad**	**bad**	**bad**	**11**

*Highlights results that were reclassified.

Overall, the comparator check IMFs are classified as *requires effort*, because further improvements are required in terms of robustness. Considering their high effectiveness they can be recommended. The Rudder Command Comparison IMF is the exception. Increasing the thresholds to improve the robustness of the IMF will significantly reduce the effectiveness of the IMF. The Rudder Command Comparison IMF can be replaced by the Sideslip Angle or Lateral Load Factor Hands-free Checks.

The hands-free check IMFs require further improvements in terms of robustness. Increasing thresholds and confirmation times may be sufficient. However, this will reduce their effectiveness, which is already limited due to the constraining conditions[4] “is hands-free” and “is normal flight envelope”. Overall, the hands-free check IMFs are classified as *requires effort*. However, it is questionable if the constraining conditions are met in a realistic scenario. For example, after an aircraft upset due to a failure, the pilot may take countermeasures. The condition “is hands-free” may change to FALSE before the failure can be detected. Also, all investigated failures are detected by other IMFs that are more effective and robust. Therefore, it is considered that most hands-free check IMFs can be replaced by other concepts, although these IMFs have shown to be able to detect FCL failures. An exception is the Bank Angle Hands-free Check[5], for which the condition “is normal flight envelope” does not apply. This IMF showed to be effective and robust and is therefore recommended. Also, the Sideslip Angle and Lateral Load Factor Hands-free Checks can be recommended to detect failures that affect the rudder command. In this case the condition “is hands-free” is equivalent to “no pedal inputs applied”.

The sign check IMFs require further improvements in terms of robustness. Increasing thresholds and confirmation times may be sufficient. However, this will reduce their effectiveness. Overall, the sign check IMFs are classified as *requires effort*. These IMFs are suitable to detect failures that lead to control reversal. However, these type of failures can also be detected by the comparator check IMFs.

The protection function check IMFs did not prove to be very effective. This is partly due to the selected test conditions, which were mainly within the normal flight envelope, and to the selected thresholds of the IMFs that require further tuning. These IMFs require more development effort to achieve an acceptable level of robustness and effectiveness. It has to be investigated if protection function checks can supplement the IM-FCL to increase effectiveness in the corners of the flight envelope. Therefore, these IMFs are classified as *recommended* or *requires effort.*

The Aileron Command Sign Check did not prove to be effective nor robust. Although, the robustness may be improved by adjusting the thresholds of the IMF, it remains questionable if the monitor can achieve acceptable effectiveness. Also, all failures could be detected with other IMFs. Therefore, the Aileron Command Sign Check is classified as *not recommended*.

[4] This condition is required to allow a prediction on the aircraft behaviour.

[5] This IMF monitors whether the bank angle exceeds its protected value during hands-free conditions.

4 Conclusion

The evaluation of the proposed Independent Monitor Functions (IMFs) in terms of effectiveness, robustness and implementation effort allows the identification of the most suitable IMFs. It is important to note that the results of the robustness and effectiveness evaluations described in references [6] and [7] are highly dependent on the selected test conditions. Therefore, the results presented in this document are only valid for the test conditions investigated.

All limit check IMFs can be recommended. The five IMFs can detect failures that lead to extreme aircraft attitudes and exceedance of the safe flight envelope limits with high effectiveness. The Pitch Angle Limit Check is redundant to the Overspeed, Normal Load Factor and Angle of Attack Limit Checks and can replace them without reducing the effectiveness of the Independent Monitor of FCL (IM-FCL)[6]. However, this may not be the case for other failure conditions that were not investigated in this project.

The limit check IMFs are robust under the simulated test conditions. And their implementation effort is low compared to other IMFs. However, limit check IMFs cannot detect failures that result in reduced manoeuvrability of the aircraft. This type of failures is best detected by the controllability check IMFs. Overall, the controllability check IMFs showed good[7] effectiveness and acceptable robustness. Although their implementation effort is higher when compared to other IMFs, these IMFs can be recommended.

Also recommended are the Pitch Trim Drift Check, Elevator Command Comparison and Aileron Command Comparison IMFs. The first showed good effectiveness and acceptable robustness. The command comparison IMFs detect command runaway like failures with high effectiveness. However, their robustness needs to be improved. Also, the constraining condition of these IMFs is that the aircraft is operated in the normal flight envelope. The risk of a command-runaway-like-failure manifesting itself in the normal flight envelope is lower than at the corners of the flight envelope. Overall, both comparator check IMFs are an indirect plausibility check of the FCL commands. They can replace hands-free check and sign check IMFs.

The Rudder Command Comparison IMF is the exception. It is questionable if the IMF can remain effective while improving its robustness. This IMF can be replaced by the Sideslip Angle or Lateral Load Factor Hands-free Checks. Both hands-free IMFs can be recommended.

Most hands-free IMFs require further improvements in terms of robustness. Also, it is questionable if the constraining conditions are met in a realistic scenario. These IMFs showed potential but require more development effort. It is considered that most hands-free check IMFs can be replaced by other concepts. An exception is the Bank Angle Hands-free Check, which showed acceptable effectiveness and robustness. Therefore, the Bank Angle Hands-free Check is recommended.

The sign check IMFs require further improvements in terms of robustness. These IMFs are suitable to detect failures that lead to control reversal. They showed potential but require more development effort.

Also, the protection function check IMFs did not show good effectiveness. These IMFs require more development effort to achieve an acceptable level of robustness and effectiveness. It has to be investigated if protection function checks can supplement the IM-FCL to increase effectiveness in the corners of the flight envelope.

The Aileron Command Sign Check did not prove to be effective nor robust. Although, the robustness may be improved by adjusting the thresholds of the IMF, it remains questionable if the monitor can be effective. Therefore, the Aileron Command Sign Check is **not recommended**.

[6] An Independent Monitor of FCL comprises several IMFs.

[7] Although the POD of these IMFs was lower than expected, their effectiveness is assumed to be high under more realistic conditions.

To summarise and for a better overview, here is the list of recommended IMFs[8]:

- **Pitch Angle Limit Check**,
- **Bank Angle Limit Check**,
- **Angle of Attack Limit Check**,
- **Overspeed Limit Check**,
- **Normal Load Factor Limit Check**,
- **Roll Rate Controllability Check**,
- **Flight path Controllability Check**,
- **Pitch Trim Drift Check**,
- **Bank Angle Hands-free Check**,
- **Sideslip Angle or Lateral Load Factor Hands-free Check**,
- **Elevator Command Comparison**, and
- **Aileron Command Comparison**.

It is important to note, that the Elevator and Aileron Command Comparison, and the Sideslip Angle and Lateral Load Factor Hands-free Check, require further development effort to achieve acceptable robustness. However, these IMFs are key to achieve high effectiveness of the IM-FCL.

The Pitch Rate Sign Check and the Angle of Attack Protection Check are also part of the reduced IM-FCL described in reference [6]. However, these IMFs are only relevant for the detection of two failures, i.e. ATHPRT and AAOA. It is assumed that these failures can be detected by the recommended IMFs under realistic conditions. In addition, significant development effort is required to improve the robustness of both IMFs. Therefore, the Pitch Rate Sign Check and the Angle of Attack Protection Check are not part of the list above.

In general, an analysis of the different failure modes (resulting from FCL development errors) considered within the FCL and their effects at aircraft level (and at the FCL outputs) has to be conducted. IMFs should be developed that can detect the failure effects at aircraft level, e.g. limit check IMFs for abnormal attitudes and controllability check IMFs for reduced manoeuvrability. A validation campaign is required to determine if the IM-FCL achieves a sufficient level of robustness and effectiveness. Effectiveness, i.e. recoverability, can be improved by adding IMFs that directly monitor the FCL output, e.g. command comparison or protection function check IMFs. The thresholds of these IMFs should be chosen large enough to maintain the robustness of the IM-FCL, but small enough to detect the failure effects that could not be detected by the first version of the IM-FCL (effectiveness).

[8] Additional IMFs may be required to improve the effectiveness of the IM-FCL in the corners of the flight envelope. The protection function check IMFs may be suitable for this purpose.