THOR M50 AND F05 SUBMARINING PROBABILITY

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ABSTRACT

During a crash test, submarining detection of the dummy is possible, either from film analysis or from measurements taken on the pelvis, especially when a force drop is observed in the Antero Superior Iliac Spine (ASIS). In the absence of submarining, it can sometimes be difficult to know if submarining was close to occur or if the configuration remained in a safe zone. In other words, was the situation really safe and stable with respect to submarining, or may small variations in test conditions lead to dramatic consequences? The objective of this study, carried out within the framework of the ABISUP project (Abdominal Injury and Submarining Prediction) was to determine a criterion for evaluating the submarining risk of occurrence for the THOR-M50 and THOR-F05 dummies. The ABISUP consortium was composed of Toyota Motor Europe (TME), University Gustave Eiffel (former IFSTTAR), University Claude Bernard Lyon 1, Transpolis, Faurecia, Humanetics, CEESAR, NHTSA and LAB PSA Renault (coordinator).

The ASIS transducers allow the measurement of the forces applied on the iliac wings in the antero-posterior direction (Fx) as well as the moments along the medio-lateral axis (My). This latter provides an indication of the position of the belt relative to the ASIS. To establish more precisely the point of application of the force, a lever arm can be calculated by dividing the moment by the force. When the value of this lever arm approaches the upper edge of the sensor, the risk of submarining increases significantly. The lever arm, identified as a submarining criterion, was calculated for a whole series of sled tests carried out with the THOR-M50 and THOR-F05 dummies and compared with the occurrence of submarining. Risk curves were constructed using the lever arm.

This paper provides a list of the tests performed, together with the maximum lever arm values calculated at the time of submarining. Risk curves are provided for both dummies.

Very few cases were identified where the criterion was decreasing prior to the occurrence of submarining. Furthermore, the range of values obtained during submarining indicated that influential factors were not accounted for. These two limitations suggested that further investigations are needed, although the proposed criterion could give a first indication of the risk of submarining.

A submarining criterion associated with risk of occurrence curves was proposed for the THOR-M50 ABISUP and THOR-F05 dummies. This criterion provides an aid to the analysis of dummy tests, which justifies its publication.

INTRODUCTION

Submarining is a binomial phenomenon. After a test, it is possible to determine whether or not it occurs. But when there is no submarining, it is difficult to know if the countermeasures implemented to prevent the occurrence of this phenomenon are robust or if the situation was just at the border between non submarining and submarining.

Drawings of NHTSA THOR M50 pelvis indicate that “The model 10387JI4 ASIS load cell is designed to provide a measurement of the force of a lap belt against the iliac spine of the pelvis. This force is measured as FX and is insensitive to the position of the belt on the iliac. The channel MY is designed to provide an indication of the position of the belt on the iliac. A reading of zero output would occur if the center of pressure of the belt is on the load cell neutral axis. If the belt is above the neutral axis a positive moment reading would occur, and a belt positioned below the neutral axis would produce a negative bending moment output." This description suggests using these measures to assess the risk of submarining.

Serra M. and Parera N. [1] analyzed sled tests performed with an HIII F05 dummy and found that the lever arm calculated by dividing the moment by the force measured by the ASIS sensors was a good indicator of the risk of submarining. They determined that the risk was critical for a lever arm value greater than 14 mm and high between 12 and 14 mm.

In 2019, Renner and Sharma [2] studied different submarining indicators on the THOR M50 and HIII F05 dummies, as well as on the human body model THUMS. Their study, based on simulation results, allowed them to select the lever arm calculated by making the ratio of moments by forces measured by the ASIS sensor as the most relevant and easy to measure.

Sled tests on the THOR M50 ABISUP and THOR F05 dummies being performed in the framework of ABISUP, it was decided to calculate this criterion and to establish risk curves for each of the dummies. The ABISUP consortium was composed of Toyota Motor Europe (TME), University Gustave Eiffel (former IFSTTAR), University Claude Bernard Lyon 1, Transpolis, Faurecia, Humanetics, CEESAR, NHTSA and LAB PSA Renault (coordinator).

The THOR M50 ABISUP dummy has an abdomen modified to be equipped with Abdominal Pressure Twin Sensors (APTS) of the same type as those used in the Q child dummies and is described by Beillas et al [4]. It should be mentioned that the ABISUP abdomen did not modify the dummy kinematics and therefore the results of this study could be applied to the standard THOR M50 dummy. The THOR F05 dummy is described by Wang et al [3].

METHODS

The process used in this study was as follows:

- Collect the test data
- Filter ASIS Fx and My at CFC60
- Compute the lever arm in the direction above the neutral axis: Lever arm = -My/Fx
- Keep the signal only when Fx > 0.15 Fxmax
- Keep only the positive value (belt above the neutral axis)
- Deal with censoring:
  - No submarining: right censored (status = 0)
  - Submarining: exact value of L defined at the time of submarining (status = 1)
- Construct the risk curve using the survival analysis method with a Weibull distribution defined in Equation 1.

$$P(Submarining) = 1 - exp\left(-\left[\frac{Lever\ arm}{\exp(\text{Intercept})}\right]^{\frac{1}{\exp(\log\_scale)}}\right) \qquad \text{Equation (1)}$$

The sled tests used in this study for the THOR M50 ABISUP were the sled tests using vehicle seats performed by Faurecia, Virginia Tech-NHTSA and TMC and described in Beillas et al. [4]. THOR F05 tests were also sled test using vehicle seats performed by Faurecia, TMC and NHTSA.

RESULTS

Experimental dataset

Data provided in Table 1 is for THOR M50 ABISUP and data in Table 2 is for THOR F05. The lever arm at the time of submarining (lever arm@time of SM) is either the value of the lever arm at the time of submarining when applicable, or the maximum value of the lever arm over time when there is no submarining. Note that some of the lever arm values are equal to 0: they actually correspond to negative lever arm values. The values are provided for each side and may differ slightly for the same test. Note that for tests ABISUP_16 to ABSIUP_19 on THOR F05, the left ASIS measurements failed.

Table 1.
Data for THOR M50

Reference	**Test**	**Side**	**Maximum Lever arm (mm)**	**Submarining**	**Time of SM (ms)**	**Lever arm@time of SM (mm)**
Faurecia	ABISUP03	L	6	1	72	3
Faurecia	ABISUP03	R	6	1	72	6
Faurecia	ABISUP05	L	0	0		0
Faurecia	ABISUP05	R	0	0		0
Faurecia	ABISUP07	L	0	0		0
Faurecia	ABISUP07	R	0	0		0
Faurecia	ABISUP09	L	11	1	57	8
Faurecia	ABISUP09	R	4	1	57	4
TMC	TMC2	L	2	0		2
TMC	TMC2	R	4	0		4
TMC	TMC3	L	2	0		2
TMC	TMC3	R	5	0		5
TMC	TMC4	L	0	0		0
TMC	TMC4	R	4	0		4
TMC	TMC5	L	11	0		11
TMC	TMC5	R	13	0		13
TMC	TMC7	L	19	1	62	14
TMC	TMC7	R	11	1	54	11
TMC	TMC8	L	14	1	63	14
TMC	TMC8	R	11	1	52	11
TMC	TMC9	L	4	1	100	3
TMC	TMC9	R	9	1	97	8
NHTSA	V1-1	L	7	0		7
NHTSA	V1-1	R	6	0		6
NHTSA	V13-1	L	8	1	74	8
NHTSA	V13-1	R	19	1	74	12
NHTSA	V14-1	L	6	0		6
NHTSA	V14-1	R	11	0		11
NHTSA	V15-2	L	5	0		5
NHTSA	V15-2	R	14	1	74.9	12
NHTSA	V19-1	L	8	0		8
NHTSA	V19-1	R	11	1	73.7	9
NHTSA	V1-2	L	5	0		5
NHTSA	V1-2	R	8	0		8
NHTSA	V13-2	L	13	1	61.1	9
NHTSA	V13-2	R	32	1	58.5	11
NHTSA	V14-4	L	9	0		9
NHTSA	V14-4	R	12	0		12
NHTSA	V15-4	L	12	1	74.4	11
NHTSA	V15-4	R	17	1	65.8	12
NHTSA	V19-4	L	13	1	85.3	12
NHTSA	V19-4	R	9	1	73.8	9

Table 2.
Data for THOR F05

Reference	Test	Side	Maximum Lever arm (mm)	Submarining	Time of SM (ms)	Lever arm@time of SM (mm)
TMC	TMC_Sled_03	L	0	0		0
TMC	TMC_Sled_03	R	5	0		5
Faurecia	ABISUP_11	L	2	0		2
Faurecia	ABISUP_11	R	7	0		7
Faurecia	ABISUP_12	L	3	0		3
Faurecia	ABISUP_12	R	8	0		8
Faurecia	ABISUP_16	R	42	1	NA	N/A
Faurecia	ABISUP_17	R	31	1	60	20
Faurecia	ABISUP_18	R	29	1	73	24
Faurecia	ABISUP_19	R	31	1	73	22
NHTSA	S191211-1	L	5	0		5
NHTSA	S191211-1	R	5	0		5
NHTSA	S191216-1	L	17	1	80	14
NHTSA	S191216-1	R	18	1	80	17
NHTSA	S200117-1	L	20	1	58	13
NHTSA	S200117-1	R	28	1	58	20
NHTSA	S210727-1	L	0	0		0
NHTSA	S210727-1	R	2	0		2
NHTSA	S210728-1	L	0	0		0
NHTSA	S210728-1	R	2	0		2

Analysis of signals

<u>No submarining case</u>. Figure 1 shows a typical case without submarining (ABISUP 05). The lever arm remains negative, indicating that the belt applies a force passing below the center of the ASIS sensor. This case illustrates a very safe situation from a submarining perspective.

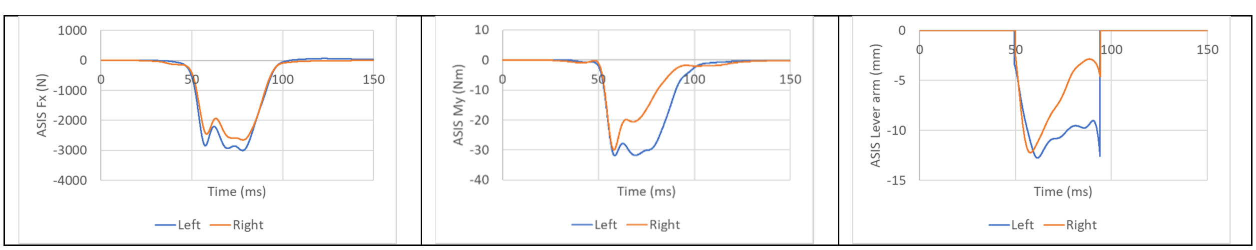

Figure 1. No submarining case ABISUP 05.

<u>Submarining cases</u>. Figure 2 and Figure 3 show two typical cases of submarining (ABISUP 09 and ABISUP 03). In the first case, the lever arm remains positive, indicating loading directly above the center of the

ASIS sensor. In the second case, the belt first loads the pelvis below the center of the sensor (negative lever arm) and then loads the pelvis above the sensor, entering the submarining zone.

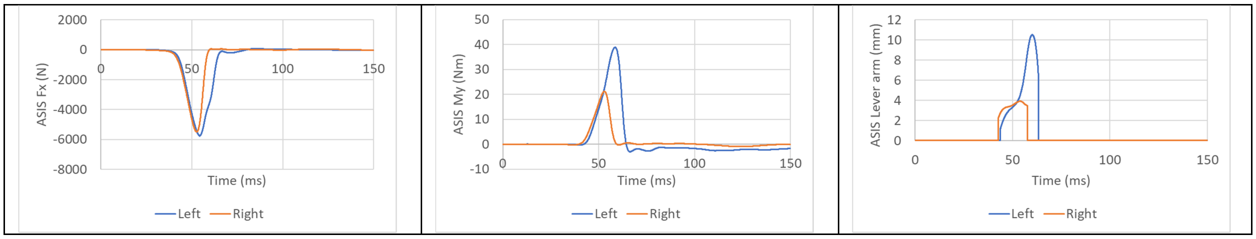

Figure 2. Submarining case ABISUP 09.

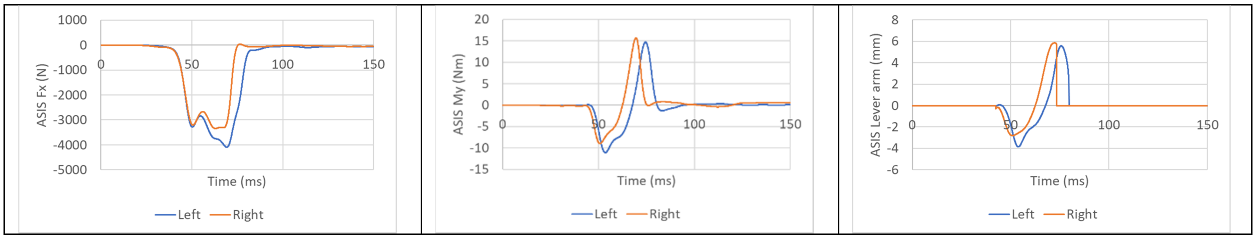

Figure 3. Submarining case ABISUP 03.

Risk curves

<u>THOR M50</u>. Figure 4 shows the submarining risk curve obtained for the THOR M50 ABISUP dummy (Intercept = -4.4639; Log_scale = -1.2934)

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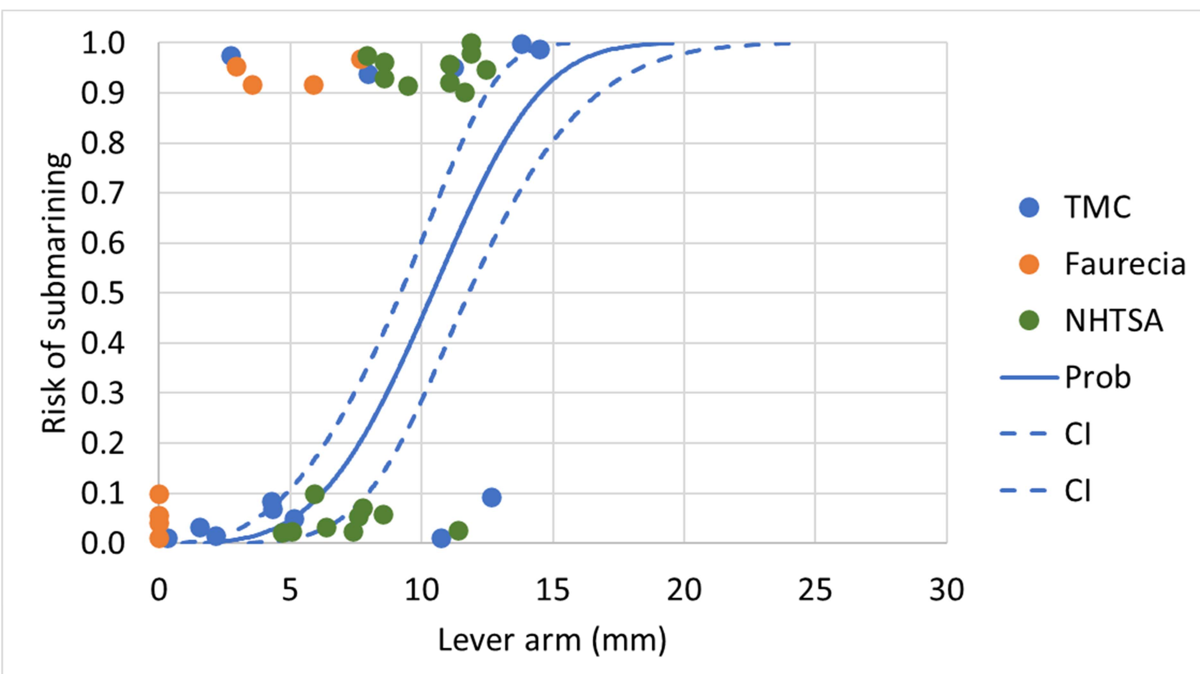


Figure 4. Submarining risk curve for the THOR M50 as a function of the lever arm at the time of submarining. CI stands for confidence interval.

THOR F05. Figure 5 shows the submarining risk curve obtained for the THOR F05 dummy (Intercept = -3.9125; Log_scale = -1.7993).

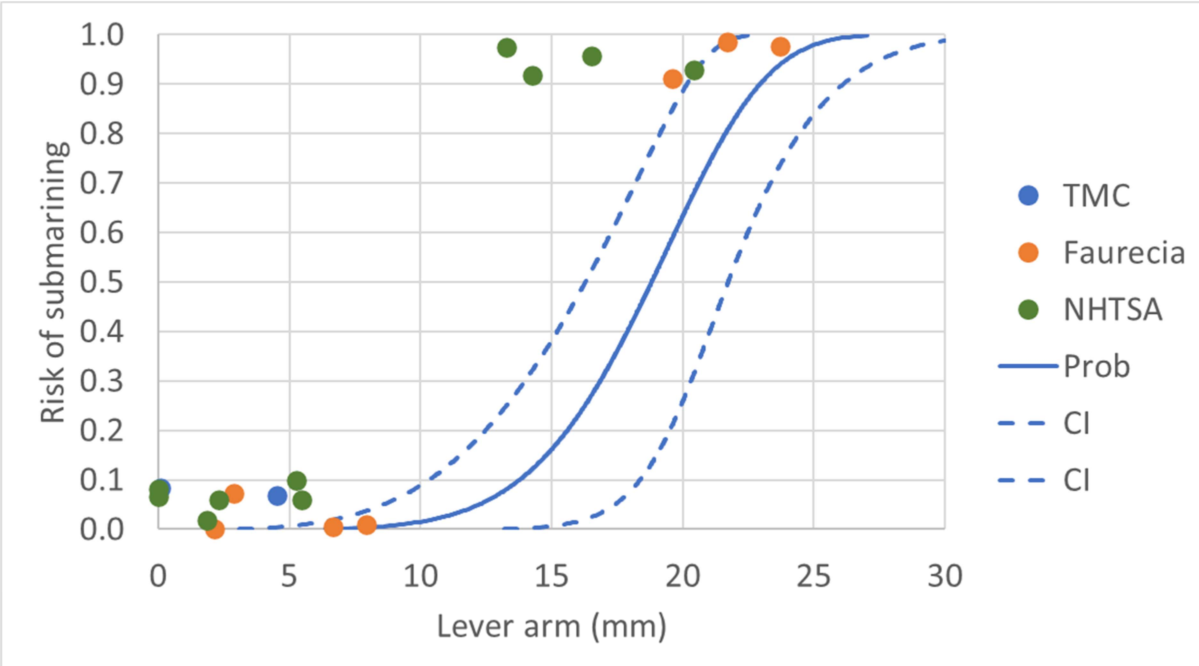


Figure 5. Submarining risk curve for the THOR F05 as a function of the lever arm at the time of submarining. CI stands for confidence interval.

DISCUSSION

Censoring of data

Cases with no submarining are right censored: it is not possible to know up to which level they would not submarine. On the contrary, cases with submarining provide exact data: the lever arm corresponding to submarining is known. This is the reason why the risk curves are centered on the submarining cases and not at the transition between no-submarining cases and submarining cases, as it would be the case if both submarining and no-submarining cases were censored.

Questionable signals

The lever arm decreased during the crash in two cases among the 20 tests performed on THOR F05. Those two cases are shown in Figure 6. This is a concern, since it is expected that the submarining occurs when the lever arm increases and overpass a threshold. However, this situation, although unexplained, is very rare and does not call into question the relevance of the criterion.

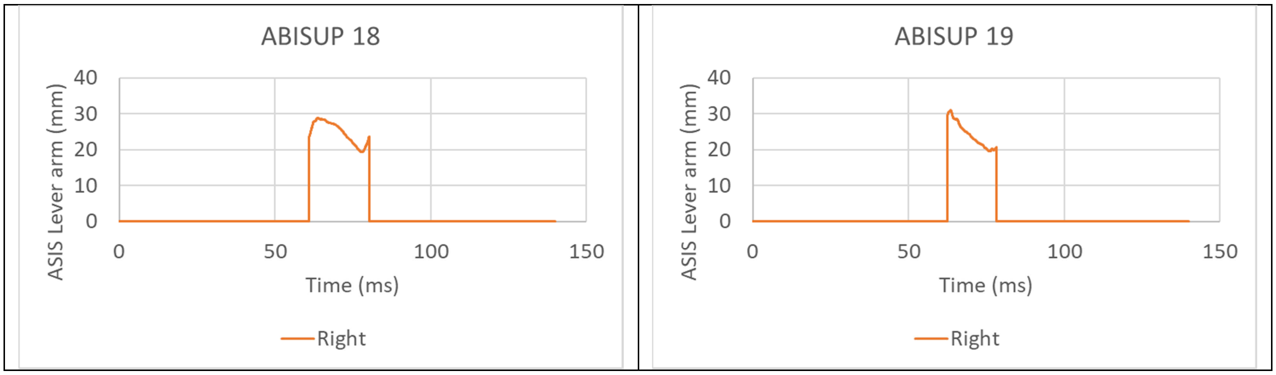


Figure 6. **Lever arm curves with concerns.**

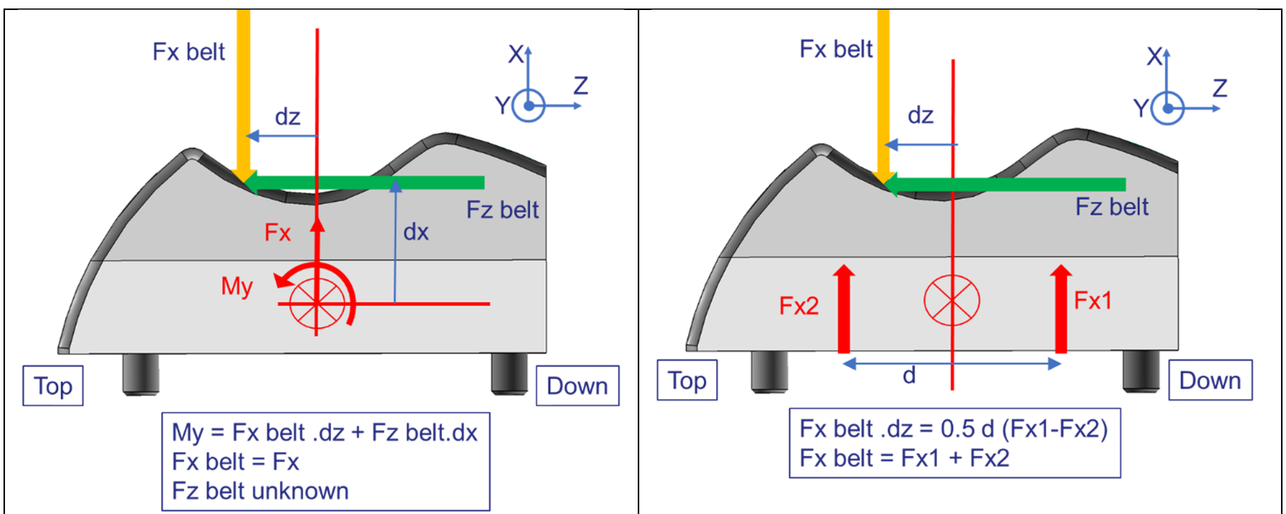
Dispersion of lever arm values

The range of lever arm values obtained at the time of submarining is quite large, while it could be expected to find a unique value. This indicates that influential factors were not accounted for or that the calculation of the lever arm is questionable.

Perspectives

The calculation of the lever arm from the moment My and the force Fx does not take into account the contribution of the force Fz in the moment My. However, this force Fz is unknown, which introduces an error in the calculation of the lever arm.

One solution to this problem would be to use the same arrangement as for the sensors of the HIII child dummies (Figure 7) which measures two Fx forces and allows for more accurate calculation of the lever arm.



THOR ASIS transducer Lever arm = - My/Fx	H3 Child ASIS transducer Lever arm = 0.5*d*(Fx2-Fx1)/(Fx1+Fx2)

Figure 7. THOR and HIII child ASIS transducers.

SUMMARY AND CONCLUSIONS

Risk curves indicating the probability of sustaining submarining in frontal crash tests were provided for the THOR M50 ABISUP and the THOR F05. The criterion is also applicable to the standard THOR-50M.

While the authors had concerns with the large range of the criterion at the time of submarining, they consider the results can help in the design of restraint systems and plan to investigate alternatives to improve the accuracy of the criterion, for instance using load cells like the ones used on the Hybrid III child dummies.

In addition, it could be interesting to investigate further the possibility of combining the measurement of the lever arm on the dummy with the submarining of the paired PMHS. The same could be done for HBMs, relating HBM lever arm and PMHS submarining.

ACKNOWLEDGMENTS

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