*ALE_STRUCTURED_FSI The New S-ALE FSI Solver

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Abstract

The LS-DYNA® Structured ALE solver is developed in 2015. It is faster and more stable; uses less memory and storage; its input format is cleaner and much less confusing. It has been well received by users studying behavior of fluids, and especially their interaction with structures.

*During the past two years, the author worked on a new fluid-structure interaction (FSI) package dedicated to be used with S-ALE solver. The objective is to shorten the running time, stop leakage, and make the input deck user friendly. In this paper this new FSI package, together with its keyword -- *ALE_STRUCTURED_FSI is introduced.*

Introduction

Until now, FSI in S-ALE solver is done through the keyword *CONSTRAINED_LAGRANGE_IN_SOLID (CLIS). It has several drawbacks.

1. While most of time leakage could be detected and cured, it does fail to prevent leakage in certain kind of engineering problems, such as blast.
2. Its MPP implementation is not optimized, especially for problems with multiple *CLIS cards.
3. *CLIS card serves too many functions. It is used to do a) penalty based FSI simulations; b) beam constrained in solid simulations like rebar enforced concrete; c) porous media. This multi-role brought the keyword with 38 parameters and 22 manual pages. It has caused way too much confusion in our users and too many input errors.

Starting from early 2018, the author started to work on a new penalty-based FSI package with a leaner code. The main goal is to automatically detect and prevent leakage with no user intervention required. To achieve that, a new leakage prevention algorithm is proposed and implemented. Other algorithm improvements are also done to better work together with the new algorithm. Secondly, MPP communications are carefully designed and strategically planned for better efficiency. "Non-blocking" and "groupable", two ideas originated by Brian Wainscott and Zhidong Han, and implemented in LS-DYNA MPP contact, are implementation to the new S-ALE FSI package. Thirdly, efforts are done to eliminate input parameters by either adding popular functions such as edge coupling to default; or by picking the optimal value through automated algorithm. For the latter, number of coupling points per segment is a good example.

Keyword

The new keyword is of the following format. To ensure a smooth transition from *CLIS to the new keyword, we placed all parameters at same locations.

*ALE_STRUCTURED_FSI							
SLAVE	MASTER	SSTYP	MSTYP				MCOUP
START	END	PFAC			FLIP		

"SLAVE" and "SSTYP" give us the structure Part/PartSet/SegSet ID; "MASTER" and "MSTYP" the fluid mesh Part/PartSet ID. "MCOUP" tells us which fluid (ale multi-material group, or AMMG) the structure is coupling to. "FLIP" is to flip the normal of the structure segments as we require the segment normal points to the fluid it couples to. "START" and "END" mark the starting and end time.

"PFAC" is used to choose the penalty stiffness. User can provide either a load curve or a fraction. Among the two choices, load curve is always encouraged. Fraction option is kept for backward compatibility.

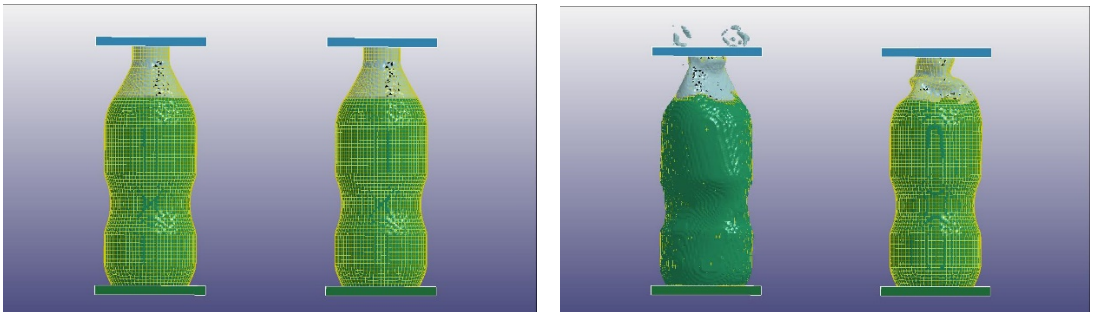
We could see from the above that there are totally 9 parameters in the new keyword format. And out of these 9 parameters, there is only one – "PFAC" needs parameter tuning. Some of parameters no longer used are listed below.

1. Coupling type: ALE FSI is done through penalty coupling (CTYPE=4). In *ASF the choice is always penalty.
2. Number of coupling points: *ASF, at the initialization phase, measures the dimension of structure segments and fluid mesh size. Then through an internal calculation to make sure enough coupling points placed on structure segments to guard against fluid flow, it determines the value.
3. Leakage control flag: Leakage is automatically detected and cured without human intervention. No flag needed anymore.
4. Normal type: This normal type was developed in *CLIS to test if different choices of normal could better prevent leakage. It is no longer needed.
5. Edge coupling: Edge coupling is automatic. Exposed edges from shell segments are picked and coupled with fluid.
6. Eroding coupling: In *CLIS, eroding coupling for solid structure parts is assigned with a different coupling type (CTYPE=5). This is because the eroding coupling allocated memory for all potential coupling segments including interior solid faces. It is very wasteful so in order to keep this waste minimum, users are asked to separate erosive and non-erosive parts and put them in different coupling cards with different CTYPEs. In the new *ASF, new memory allocation is designed to minimize memory waste and hence no need to make eroding coupling an option. Eroding is always considered. Once a surface solid element erodes, new coupling segments are generated and new memory allocated.

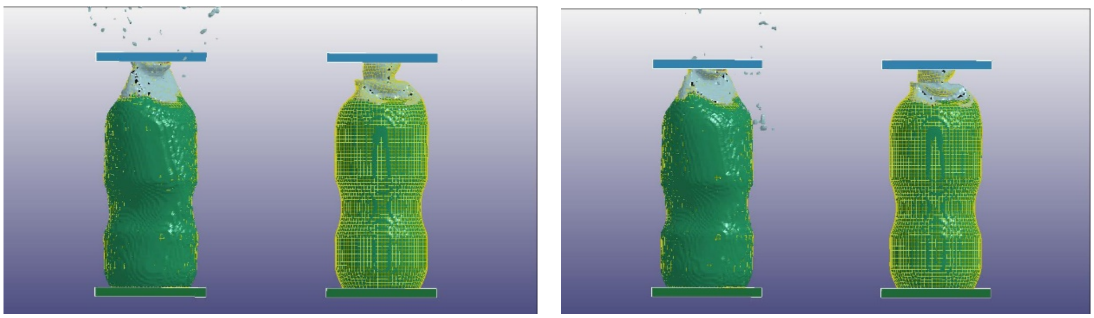
Test Cases 1: Leakage Prevention

Tests so far showed the new algorithm detected and prevented leakage much better. The following two rows of figures show a bottle under compression loading, using *CONSTRAINED_LAGRANGE_IN_SOLID and *ALE_STRUCTURED_FSI to perform FSI simulations, respectively. Curtsey: Sriraghav Sridharan, Application Engineer, ANSYS ACE.

We could see that air is flowing out of the bottle under compression in case of *CLIS while they were kept inside in *ASF simulation. Left: CLIS; Right: ASF



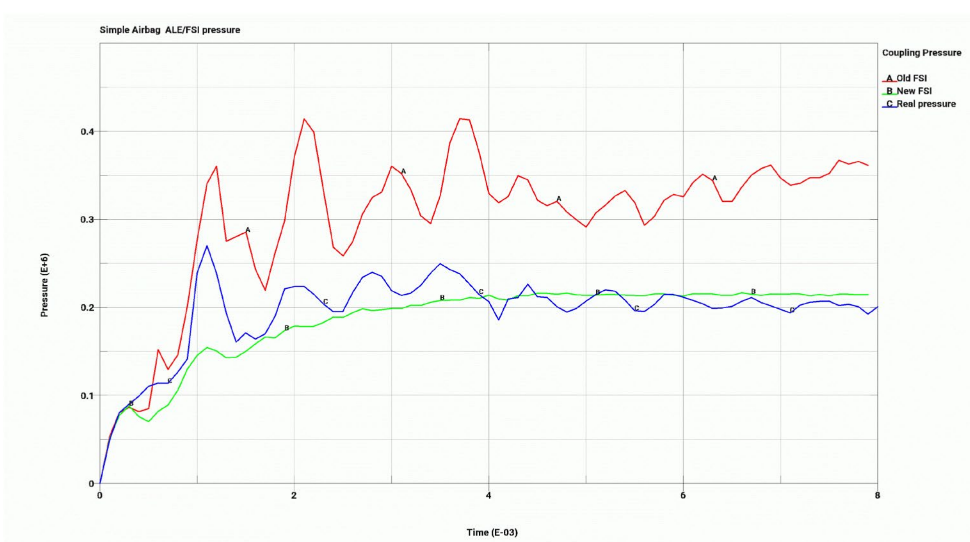
t=0 t=0.0184



t=0.028 t=0.04

Test Case 2: Leakage and FSI pressure

Another test case is a simple spherical airbag being inflated. Its input deck is at http://ftp.lstc.com/anonymous/outgoing/hao/salecpl/bag/. Both *CLIS and *ASF could cure the leakage, but somehow the coupling pressure is not in the *CLIS case. In the figure below, red line is the *CLIS FSI pressure; the green *ASF; and the blue one is the pressure difference between the gas inside and air outside. The result got by *CLIS is about 1 bar higher than the real value. We suspect that pressure over-estimated might come from some flaws in the old leakage algorithm but no conclusion has been reached yet.



Test Case 3: MPP Efficiency

This test case is a fuel tank sloshes and then is impacted by a projectile. Its input deck is at http://ftp.lstc.com/anonymous/outgoing/hao/salecpl/tankslosh/. It contains 3 coupling cards with 41k shells and 91k ALE elements. A run with 48 cores for two cases, one with *CLIS, another with *ASF, yields the following timing data.

*ALE_STRUCTURED_FSI	*CONSTRAINED_LAGRANGE_IN_SOLID
S-ALE FSI .... 5.1793E+02 S-ALE FSI ID 1 .. 4.5567E+01 S-ALE FSI ID 2 .. 8.0366E+00 S-ALE FSI ID 3 .. 4.4024E+01 S-ALE Advection ...... 2.0511E+02	ALE FSI Algorithm .... 1.8111E+03 FSI ID 1 ... 7.2176E+02 FSI ID 2 ... 4.7892E+02 FSI ID 3 ... 6.1037E+02 S-ALE Advection ...... 1.7736E+02
1188 seconds for 37865 cycles	2558 seconds for 37523 cycles

We could see that the *ASF run spent only less than 30% of running time of *CLIS. It proved the enhanced MPP efficiency for multiple coupling cards.

Conclusions

We introduced the new FSI package for LS-DYNA Structured ALE solver in this paper. This new FSI package is dedicated to be used with S-ALE solver only. Tests show that the new package better prevents leakage, runs faster and is more accurate. It is with a new keyword called *ALE_STRUCTURED_FSI and contains way less parameters and is much more user-friendly. The S-ALE developer at Ansys Livermore is committed to continually work with our users to improve.