

SIMULATING HYDROSTATIC PRESSURE

*INITIAL_ALE_HYDROSTATIC *ALE_AMBIENT_HYDROSTATIC

(1) TRADITIONAL HYDROSTATIC P



TRANSIENT INITIALIZATION OF HYDROSTATIC PRESSURE:

In a typical model simulating a large body of deep water analysis where hydrostatic pressure is important, the basic traditional approach is to:

- Use *BOUNDARY_SPC_SET to constrain of the nodes on the free surfaces of the ALE mesh. The 4 lateral sides and bottom are fixed simulating a "pool-like" condition. The top surface is typically free (say, open to air).
- Define gravity via *LOAD_BODY_(dir) to create the hydrostatic condition.
- Apply some damping to reduce P oscillations
- Run this transiently to let hydrostatic P settles to its "initial state" before apply dynamic BC's (ship motion, detonation, etc.)

1-SLICE SIMPLIFIED MODEL



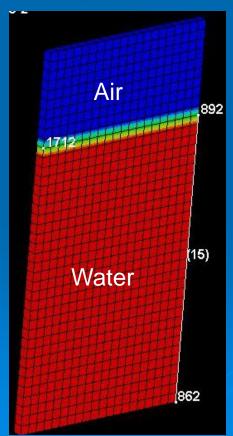
Consider a 1-element thick or slice model (in Z-direction) as a

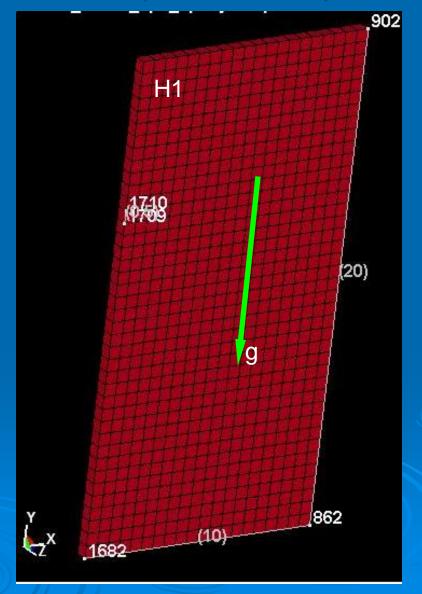
demonstration example.

Domain Width = 10m

Domain Height = 20m

Element Size = 0.5m





PART/MATERIAL DEFINITIONS



Part H1 is the initial 1 atm air background mesh = ALE domain.

```
*PART
H1 = AMMG1 = ALE air on top:from NID 851 up to NID 1722 AIR (Kg-m-s) @ T=25C
                           mid
                                   eosid
                                              hgid
       pid
               secid
                                                                 adpopt
                                                         grav
                                                                              tmid
                             1
                                       1
*SECTION SOLID
    secid
              elform
                           aet
                  11
*MAT NULL
       MID
                  RO
                            PC
                                                                 YMBEAM
                                      MU
                                              TEROD
                                                        CEROD
                                                                           PRBEAM
             1.1845
                         -10.0 1.8444E-5
                                                0.0
                                                                    0.0
                                                          0.0
                                                                              0.0
*EOS LINEAR POLYNOMIAL
    EOSID
                  C0
                           C1
                                     C2
                                                 C3
                                                           C4
                                                                               C6
                           0.0
                                    0.0
                                                0.0
                                                          0.4
                                                                    0.4
                 0.0
                                                                              0.0
                 V0
2.533125E5
                 1.0
*HOURGLASS
      hgid
                 ihq
                                     ibq
                                                 q1
                                                           q2
                                                                     qb
                            qm
                                                                                qw
                        1.0E-9
```

NOTE: For ideal gas *EOS_LINEAR_POLYNOMIAL (ELP) or *EOS_IDEAL_GAS (EIG) may be used. If ELP is used, define only: C4=C5=(γ-1), and use E0 & V0 to initialize the thermodynamic state - DO NOT define C0 for ideal gas!

PART/MATERIAL DEFINITIONS



Use *INITIAL_VOLUME_FRACTION_GEOMETRY to fill in water in the region of $y:\{0 \rightarrow 15m\}$.

```
*PART
H2 = AMMG2 = ALE surrounding water below NID 851
      pid
               secid
                           mid
                                   eosid
                                              hgid
                                                                adpopt
                                                        grav
                                                                             tmid
                             2
                                       2
*SECTION SOLID
    secid
             elform
                           aet
                  11
*MAT NULL
$
      mid
                                             terod
                                                       cerod
                                                                              pr
                            pc
                                                                    ym
                      -10000.0 0.8684E-3
                                                       0.0
             998.210
                                             0.0
                                                                   0.0
                                                                              0.0
*EOS LINEAR POLYNOMIAL
    eosid
                                                                               c6
        2 101325.0
                       2.25E9
                                   0.0
                                               0.0
                                                         0.0
                                                                    0.0
                                                                              0.0
$
     0.000
               0.000
```

NOTE: ELP may be used if the pressure range is within the linear limit. If nonlinear compression occurs *EOS_GRUNEISEN (EG) should be considered. Again, {E0, V0} pair should be used to initialize the thermodynamic state of the material.

$$P_{t=0} = P_0 = C_0 + C_1 \mu_{t=0} = C_0 + C_1 \left(\frac{1}{\nu_{t=0}} - 1 \right)$$

BOUNDARY CONSTRAINTS



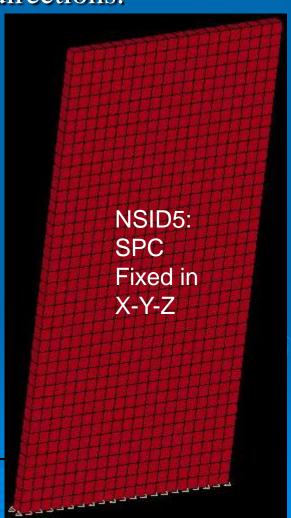
NSID1: Z degree of freedom (Z-DOF) is required for all nodes.

NSID4: The 2 vertical faces will have slip condition.

NSID5: The bottom face will be fixed in all 3 directions.







*BOUNDARY SPC SET



The free surfaces of the ALE domain must be constrained to simulate a pool-like condition. This can be done by specifying the nodal constraints for nodes on the free surfaces.

The 3 nodal constraints can be applied by the following keyword:

\$=======		=======	=======	=======			
*BOUNDARY SPC	SET						
\$ NID/NSID	CID	DOFX	DOFY	DOFZ	DOFRX	DOFRY	DOFRZ
1	0	0	0	1	0	0	0
4	0	1	0	1	0	0	0
5	0	1	1	1	0	0	0
\$======							

Please refer to the figure in the previous slide for visualization.

GRAVITY LOADING



Gravity is the main force that creates the hydrostatic pressure in the fluids. It is applied by simply defining a body force.

\$===							
*LO	AD_BODY_S	Y					
\$	LCID	SF	LCIDDR	XC	ХC	ZC	
	1	9.80665					
*DE	FINE_CURV	VE.					
\$	LCID	SIDR	SFA	SFO	OFFA	OFFO	DATTYP
	1						
\$		a1		o1			
		0.000	1.00	000000			
		2.0e+5	1.00	000000			
\$===	=======	========	========	=======	=======	=======	

NOTE:

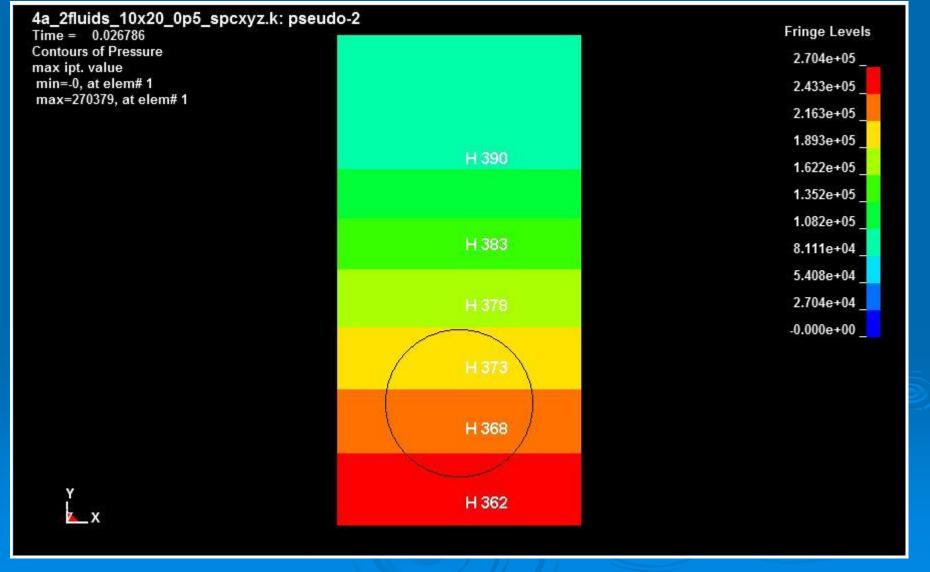
If severe loading oscillation occurs, the load curve for gravity may be ramped up over a few hundred time steps.

Hydrostatic pressure may also be initialized by a recently developed command *INITIAL_HYDROSTATIC_ALE card (IHA).

TRANSIENT INITIALIZATION



Transient gravity loading resulting in hydrostatic pressure

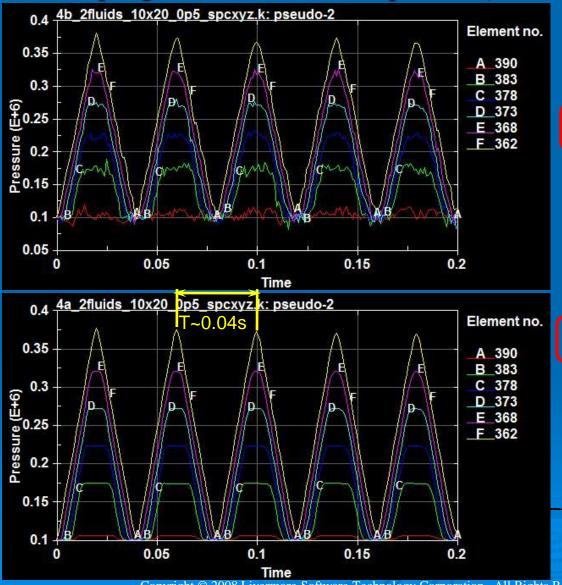


WITHOUT DAMPING



Damping seems to be important at this resolution level.

Without damping the Poscillations persist (even with double precision run)



No IHA
No Damping
Single precision
(a.k)

No IHA
No Damping
Double precision
(a.k)

(Double precision seems to only smooth out high frequency errors)

 $Period = T \sim 0.04s$

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DAMPING



Water has very high bulk modulus ~ highly incompressible. Small $\triangle Vol \Rightarrow large \triangle P \Rightarrow large P$ oscillation may occur. Oscillation may be reduced by *DAMPING_PART_MASS (viscous damping is appropriate for fluids).

```
*DAMPING PART MASS
        PID
                                          FLAG; period=T\sim0.021s \Longrightarrow Ds\sim4PI/T\sim 596.2
                   LCID
                                 SF
                             100.0
*DEFINE CURVE
      LCID
                  SIDR
                               SFA
                                            SFO
                                                      OFFA
                                                                  OFFO
                                                                            DATTYP
$
                     A1
                                             01
                 0.000
                                   1.00000000
                    2.0
                                   1.00000000
```

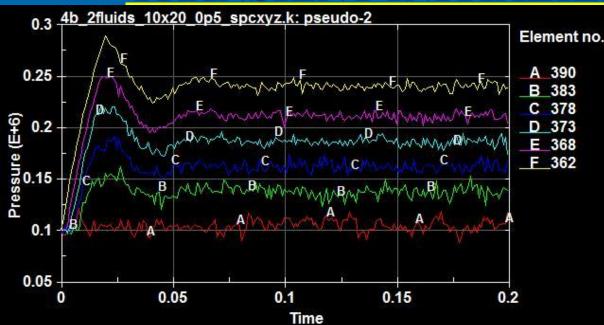
NOTE:

The damping coefficient may be crudely estimated by:

- First run a case without damping
- Plot and estimate an average P oscillation period, T ~ 0.04s
- Estimating the damping coefficient $\sim (4 \Pi/T) \sim 314$

TRANSIENT INITIALIZATION





WITH DAMPING

Double Precision

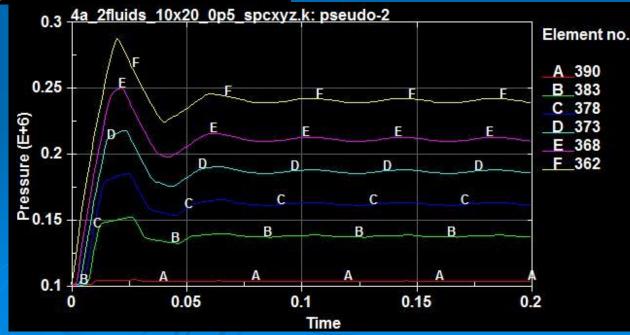
- No IHA
- Damp=100

DP smooths out high frequency errors.

 $(c_damp100.k)$

Single PrecisionNo IHADamp=100

(See figure on last page for locations)

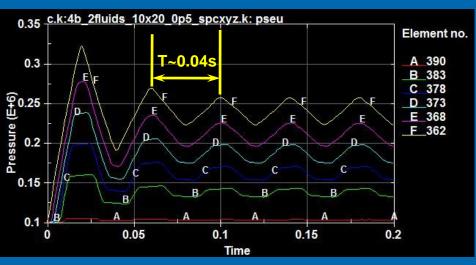


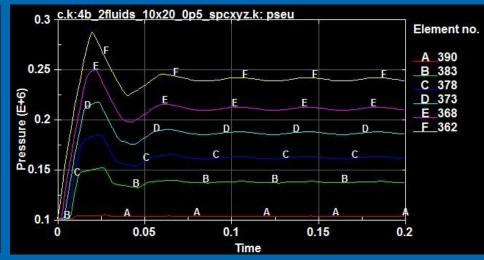
TRANSIENT INITIALIZATION



FINE TUNING DAMPING DAMP=50

DAMP=100

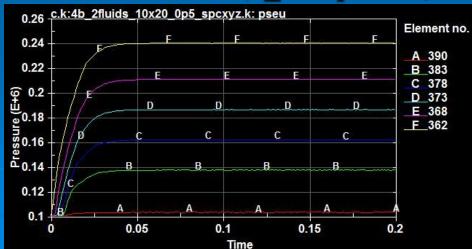




DAMP=200

c.k:4b 2fluids 10x20 0p5 spcxyz.k: pseu Element no. 0.24 A 390 0.22 B 383 C 378 0.2 0.18 0.16 D 373 D D E 368 F 362 C ₫ 0.14 0.12 0.1 0.05 0.1 0.15 0.2 Time

best = DAMP=300 (c_damp300.k)





*INITIAL_ALE_HYDROSTATIC

*INITIAL HYDROSTATIC ALE (IHA)



IHA: A more efficient hydrostatic pressure initialization approach.

Model Description:

H1 = AMMG1 = Air (background mesh)

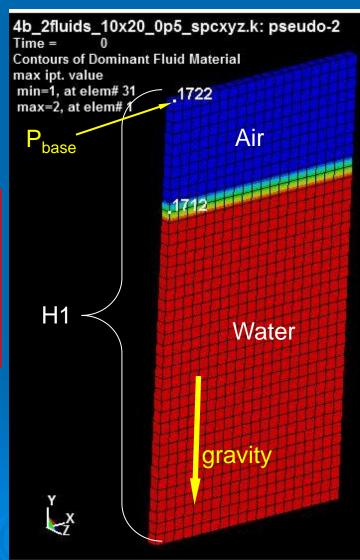
H2 = AMMG2 = Water(no initial mesh)

Top-to-Bottom materials order:

NID	MATERIAL	
1722		(top of air)
	Air above = AMMG1	(i=1)
1712		(top of water)
	<pre>water = AMMG2</pre>	(i=2)
		(bottom)

Initialize hydrostatic P based on element depth and with respect to the "reference" P at the top (or base-P). $P = P_{base} + \sum_{i=1}^{N_{AMMG}} \rho_i g h_i$

$$P = P_{base} + \sum_{i=1}^{N_{AMMG}} \rho_i g h_i$$





Translating the previous descriptions into a keyword

```
*INITIAL HYDROSTATIC ALE
                                               Reference or ambient pressure
      SID
           SIDTYPE
                      VECID
                            GRAVITY
                                       PBASE
                                               at the top of the mesh
                            9.80665 101325.0
                         11
$
          MMGBELOW
      NID
                      ALE domain or mesh to initialize hydrostatic pressure
     1722
                     Top fluid layer (AMMG1)
     1712
*DEFINE VECTOR
                     2nd fluid layer (AMMG2)
      vid
                                                                     cid
               xt
                        yt
                                  zt
                                          xh
                                                   yh
                                                             zh
                        1.0
                                 0.0
                                                   0.0
       11
               0.0
                                          0.0
                                                            0.0
          = SID defines the ALE mesh (domain) whose hydro-P
SID
            is being initialized
          = SID type: 0=PSID, 1=PID
STYPE
VECID
          = Vector ID defining the direction of gravity
GRAVITY
          = Magnitude of gravitational acceleration
          = "Base" P @ the top surface of the top fluid
PBASE
```

MMGBELOW = The AMMG that is immediately located below NID

= NID defining the top level of each AMMG

*LOAD BODY [] must be defined.

NID



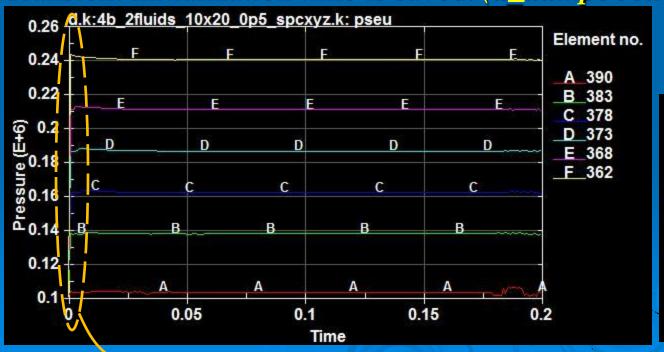
Simply adding this new feature to the previous model and run

- Define *INITIAL_HYDROSTATIC_ALE (IHA)
- Damping coefficient = 300
- Double precision

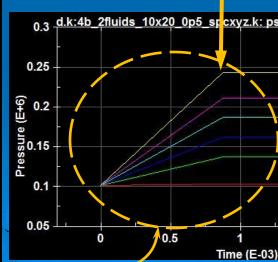
EFFECT:

Hydrostatic-P of the ALE elements are initialized very fast!

Transient initialization time is saved. (d_damp300.k)

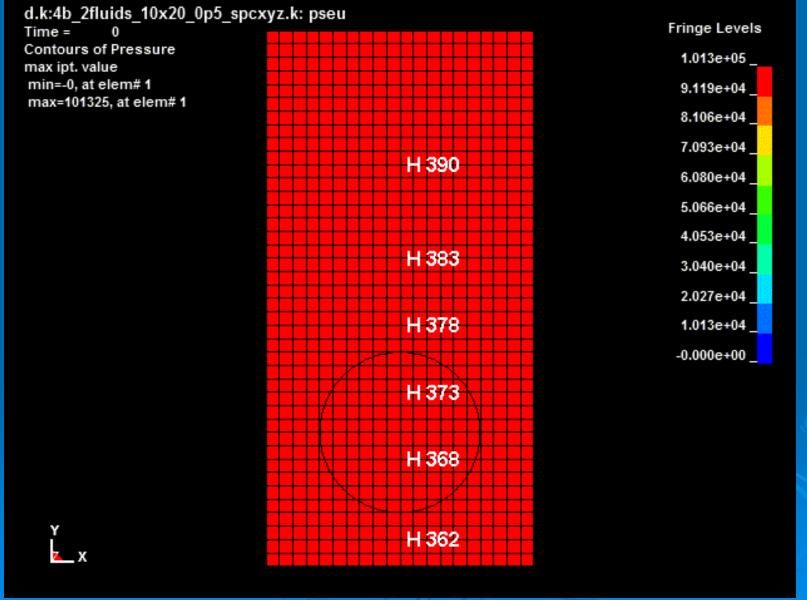


Ramping up in about 4 time steps





Pressure result from d_damp300.k ...





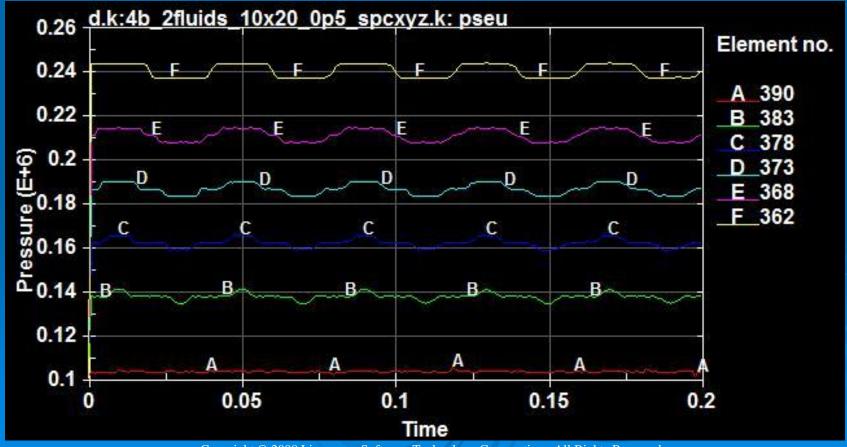
Simply adding this new feature to the previous model and run

- Define *INITIAL_HYDROSTATIC_ALE (IHA)
- Damping coefficient = 0
- Double precision

EFFECT:

Damping is still needed!

(d.k)





MULTIPLE FLUID LAYERS: (e_damp300.k)

Model Description:

H1 = AMMG1 = Air (background mesh)

H2 = AMMG2 = Water (IVFG)

H3 = AMMG3 = Water (IVFG)

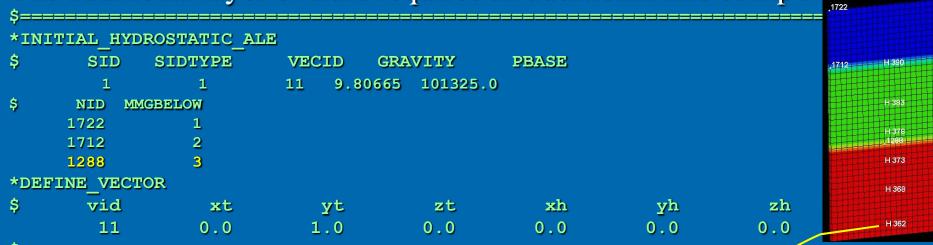
Top-to-Bottom materials order:

NID	MATERIAL		H1≺
1722	<pre>Air above</pre>	= AMMG1	(top of air)
1712	<	- AMMGI	(top of water 1)
1000	Water	= AMMG2	// S
1288	Water	= AMMG3	(top of water 2)
	<		(bottom)





The additional layer of fluid requires an additional line of input



Double precision Damp=300 With IHA

3 fluid layers (see previous page & note B & C positions)





Model Description: (f_damp300_bub.k)

H1 = AMMG1 = Air (background mesh)

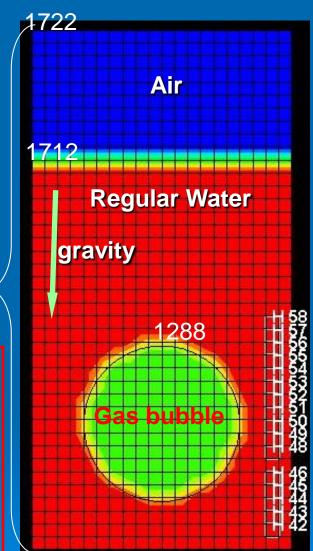
H2 = AMMG2 = Regular water (IVFG)

H3 = AMMG3 = Gas bubble (IVFG)

NO COULPING TO SHELL!

Top-to-Bottom materials order:

NID	MATERIAL	
1722	<	(top of air)
	Air above = AMMG1	
1712	<	(top of water)
	Water = AMMG2	
1288		(top of bubble)
	Gas bubble = AMMG3	
	<	(bottom)



H1



The order of the AMMGs in the IHA card is listed from top to bottom.

For this model ...

\$===	======				=======			
*INI	TIAL_HY	DROSTATIC_ALE	2					
\$	SID	SIDTYPE	VECID	GRAVITY	PBASE			
	1	1	11	9.80665	101325.0			
\$	NID	MMGBELOW	Δ.	N 4 N 4 O 4				
	1722	1←	—— A	MMG1 =	Top of air			
	1712	2 ←	——Α	MMG2 =	Top of wa	ter		
	1288	3←			- The state of the			
*DEF	'INE_VEC	TOR	—A	MIMG3 =	Top of gas	s bubble		
\$	vid	xt	уt	zt	жh	yh	zh	cid
	11	0.0	1.0	0.0	0.0	0.0	0.0	
\$===		=========		=======	========			

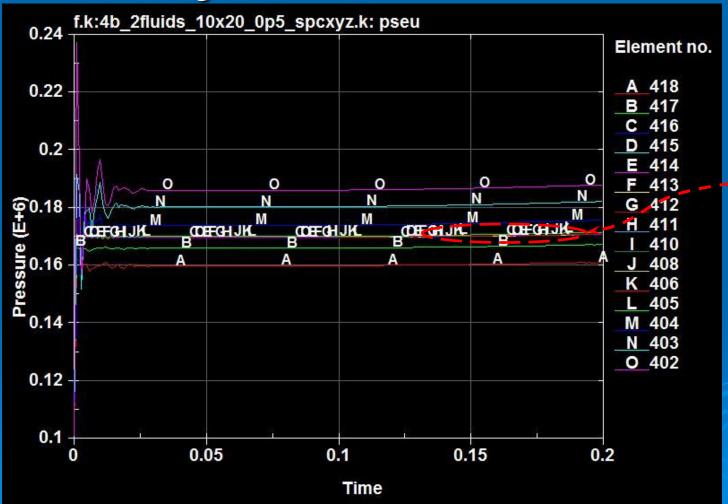
Recall

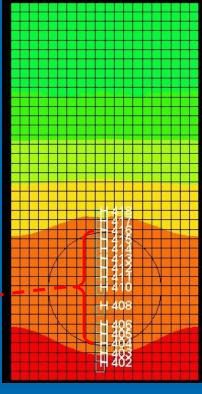
$$P = P_{base} + \sum_{i=1}^{N_{AMMG}} \rho_i g h_i$$



P INSIDE THE GAS BUBBLE:

Expected and observed no significant hydrostatic P variation in gas.



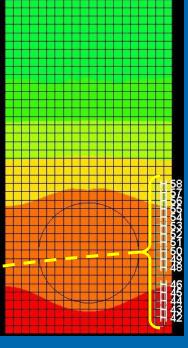




POUTSIDE THE GAS BUBBLE:

Expected and observed visible hydrostatic P variation in the liquid region.



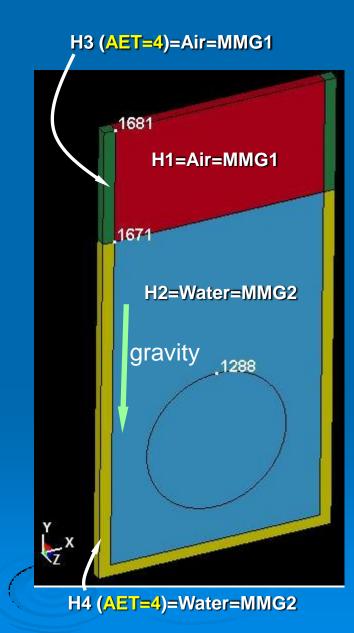






Instead of a "pool-like" condition, we want edges of the ALE domain to behave like "reservoir" with appropriate hydrostatic P. In-flow and out-flow are permitted depending on the local P field at the boundaries.

- Define a layer of "reservoir-like" part(s) surrounding the regular ALE domain.
- We have air and water so there will be 2 parts added with AET=4 defined under *SECTION_SOLID card (ambient type elements).
- WE NEED TO INTITIALIZE THESE AMBIENT PARTS → Next ...



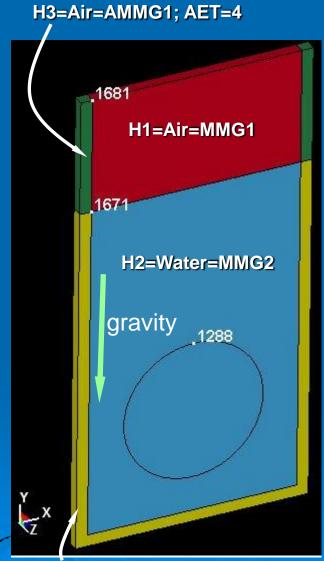


- *ALE_AMBIENT_HYDROSTATIC

 (AAH) initializes the hydrostatic P for only

 ALE ambient parts (parts with AET=4

 under *SECTION_SOLID).
- It is used <u>only</u> to define the far-field, approaching-ambient (or reservoir-like) boundary condition in the fluids **.
- Typically one or two-element layers on the free surfaces of the total ALE domain may be defined as ambient part(s).
- The pressure in these hydrostatic-reservoir parts will be constant and element-depths dependent.
- AAH has the same parameters as the IHA command.



H4=Water=AMMG2; AET=4



THREE MULTI-MATERIAL GROUPS:

H1 = AMMG1 = Air

H3 = AMMG1 = Air (ambient part, AET=4)

H2 = AMMG2 = Water

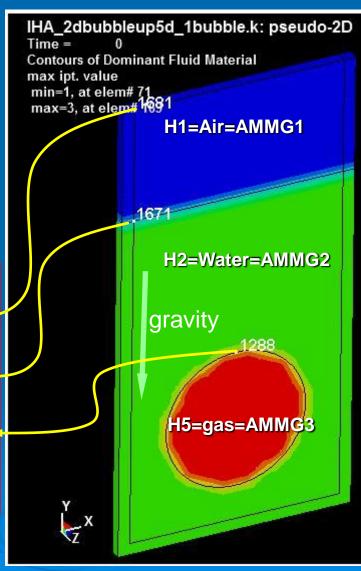
H4 = AMMG2 = Water (ambient part, AET=4)

H5 = AMMG3 = gas in bubble

Top-to-Bottom materials order:

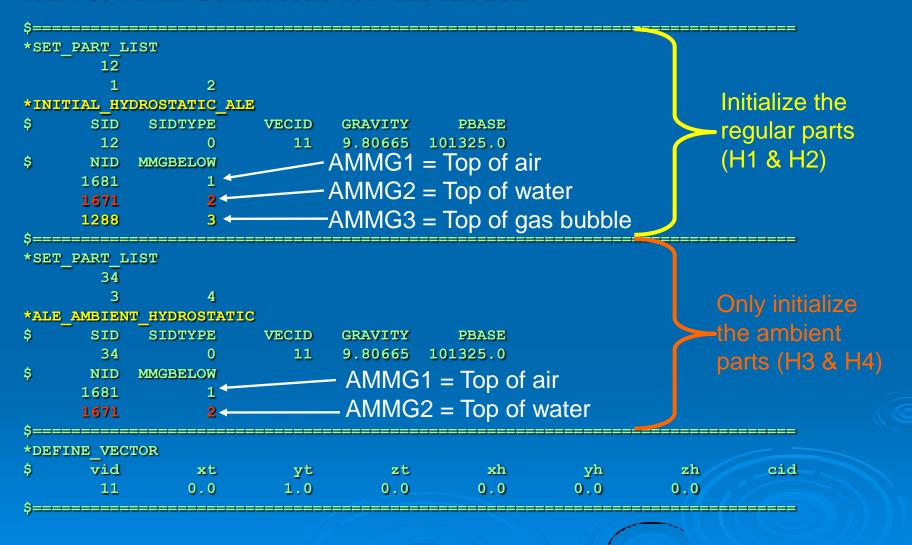
NID	MATERIAL
1681	(top of air)
	Air above = AMMG1
1671	(top of water)-
	<pre>water = AMMG2</pre>
1288	(top of bubble)
	gas bubble= AMMG3
	(bottom)

g_damp300_bub_AAH.k

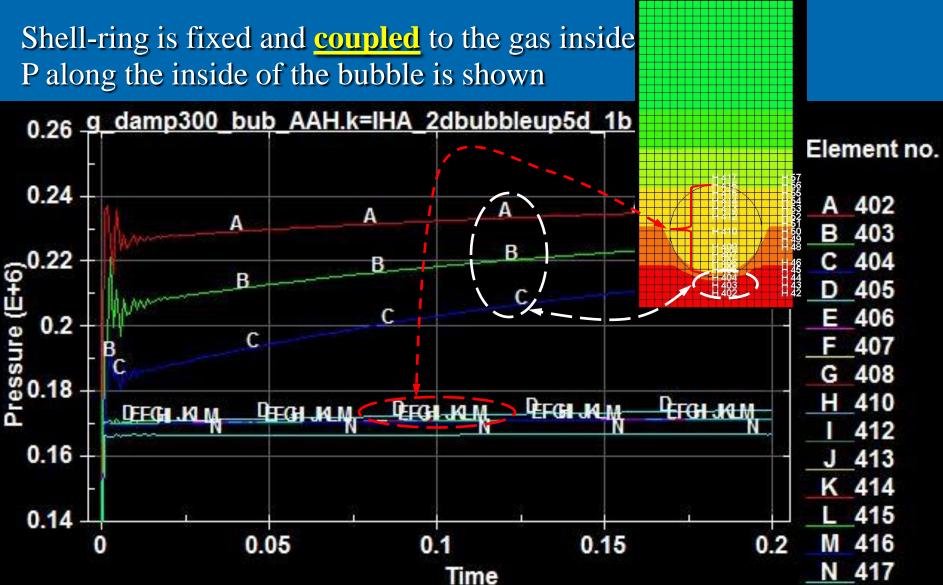




IHA & AAH definitions for this model:

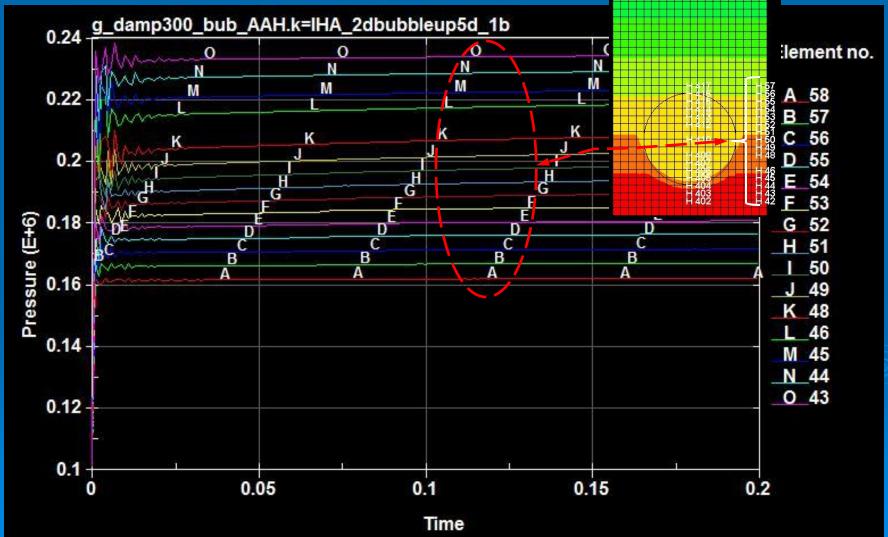






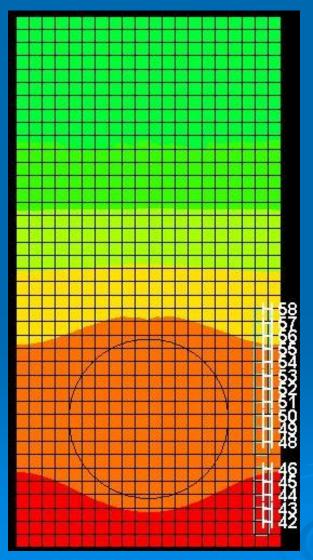




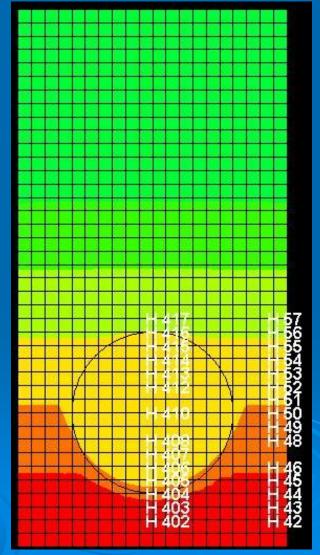




Without AAH No coupling



With AAH With coupling





SUMMARY OF INPUT EXAMPLES:

a.k Transient loading (single & double precision runs)

c_damp300.k → Transient + damp300

 $d_{amp300.k} = c_{amp300.k} + IHA (best, 2 material layers)$

 $e_damp300.k = d_damp300.k + 1$ more layer of material

f_damp300.k = e_damp300.k + layer replaced by gas bubble

 $g_{damp300.k} = f_{damp300.k} + AAH$