Pre-deployment Summary

Preparations for Dive 2 of LST were started on 13Dec2007 at 105942Z.

Flash EEPROM was erased and data storage was set to start at FlashAddr =0x0000 of page 0x08.

The status area of EEPROM was cleared to -1 and DiveNo set = 0.
Fall0 was changed from 30 minutes in Dive 1 to 15 minutes and the AbortTime was set to 13Dec2007 1400Z.

```
After this the contents of EEPROM were:
     S.tatus area:
       BTcb           -1
       BTpb           -1
      BTvac           -1
     BTdvac           -1
     BTstat           -1
     BTDkP0           -1
     BTDkP1           -1
     BTPsec           -1
     BTPcur           -1
     BTSBms
     DiveNo            0
     AbrtCd           -1

     M.ission area:
     FPchks            5
     dBarGo          490
      Fall0           15   <--was 30 minutes on Dive 1
      Ztar0          500
     Tlast0            0
      Rise0           83
     MxPsec         1800
       dTdZ           26
     mxSeek           60
     SAMmin            1
       Nsam           60
     Surfmn         1440
      XAchk          960
     FnlDiv            1
     AbrtYr            7
     AbrtMo           12
     AbrtDa           13
     AbrtHr           14
     AbrtMn            0
     EEP>
     c
     EEP>
     v
     OK EEPROM checksum
```

Then SOLO was put shut-down into low power state.

SOLO was magnetically reset at 13Dec07 111617Z:

```
Starting..
Toyo_Xmit
PTT(hx): BE  07  08  09  0A  0B  0C  0D  0E  0F  10  11  12  13  14  15
         16  17  18  19  1A  1B  1C  1D  1E  1F  20  21  22  23  24  25

C:\SOLO\MBARI_LST\HC12\start.c compiled Dec  3 2007 18:39:05

SOLO 2745 Hx: 28E58BE Dc:  80059 Tel:  2617 190 Ver: MBARI  02Dec07
RTC Year/Mon/Day= 2007/12/13 HHMMSS=111617
EEPROM CRC is  OK
CPU=758  thresh= 550 status=0000
PMP=1525  thresh= 1250 status=0000
VAC=416  status=0000
Status=0000 after batt&vac check
sbe_pts
SBE response=   -0.50,  8.9985,  2.2942

Status=0000 after SBE pts
^BIT_status=0x 0000
^    All OK
^CPU,PMP,VAC= 758 1525 416    (counts= 216 239 122 )
Dive number =   0

Select operation :
BASE MENU
ESC Quit     : U.pdate menu   : V.ersion     : H.uman Op.
E.EPROM ops : P.ump tests    : S.BE test    : D.ata proc.
A./D test   : R.T Clock      : T.oyocom     : O.ptions
B.asic BIT  : F.ull BIT      : Z. batts&vac : L.owpower
X Shut_down : M.ission start : C.omment     : 1 Flash ops
```

The SOLO mission was manually started at 13Dec07 111853Z:

```
BAS>
m
DiveNo= 1 starts hovering in 15 minutes
Check press every 5 secs to exceed 490 dBar

StartMission 13Dec07 111853Z= 250859933 secs
               <--Abort @ 13Dec07 1400Z is 9667 secs after StartMission
go_Dive # 1  cyc_num=0
Start SINK
Start go_piston for 1800 secs...End
#pist tries=1
Open air valve
sbe_fp   p= -0.46  (   -0.46)
Start fall P=-0.5
sbe_fp   p= -0.04  (   -0.04)
F      8  -0.0
RTC=250859943  tend=250860836
sbe_fp   p= -0.05  (   -0.05)
F     13  -0.0
RTC=250859949  tend=250860836
```

The communications cable was disconnected at this point and SOLO was deployed.

Deployment Notes

A 7.8kg weight was added to SOLO prior to launch. This weight was jettisoned at 400 meters. SOLO was in sole control of ballasting past this point. When the mission ended and SOLO headed for the surface, it was allowed to rise to a depth of 277 m before an ROV grabbed the unit and brought it to the surface. A 400g drop weight may have been dropped during the ascent but probably not until after the ROV had grabbed SOLO.

Recovery Summary

SOLO was awakened by the operator on 13Dec07 150325Z:

```
>>wAwakened by operator

ERR-RESET after mission start is SERIOUS problem

C:\SOLO\MBARI_LST\HC12\start.c compiled Dec  3 2007 18:39:05

SOLO 2745 Hx: 28E58BE Dc:  80059 Tel:  2617 190 Ver: MBARI  02Dec07
RTC Year/Mon/Day= 2007/12/13 HHMMSS=150325
EEPROM CRC is  OK
CPU=755  thresh= 550 status=0000
PMP=1487  thresh= 1250 status=0000
VAC=458  status=0000
Status=0000 after batt&vac check
sbe_pts
SBE response=   -0.08, 11.3193,  0.4246

Status=0000 after SBE pts
^BIT_status=0x 0000
^    All OK
^CPU,PMP,VAC= 755 1487 449    (counts= 215 233 115 )
Dive number =   1
```

The EEPROM areas were listed:

```
I.Ds
    SOLOsn         2745
    PTThex     f28e58be
    PTTdec        80059
    PTTsec           45
     CPUsn          650
     AUXsn         4650
     CTDsn          983

C.als
      Vac0          212
      Vac5          104
     CBat5          141
     CBat6          170
    PBat12          188
    PBat15          235
     Mcur0            0
     Mcur1           13
      Poff           40
     Pgain            2
      Toff            0
     Tgain            2
      Soff       -32000
     Sgain            2
      BLOK            2
       PB1           20
       PB2           40
       AV1            5
       AV2           10

B.ITvals
     CBmin          550
     PBmin         1250
     VACmn          400
    dVACmn          150
     AIRsc           60
     MCmax         5000

S.tatus
    BTcb         -1
      BTpb           -1
     BTvac           -1
    BTdvac           -1
    BTstat           -1
    BTDkP0           -1
    BTDkP1           -1
    BTPsec           -1
    BTPcur           -1
    BTSBms
    DiveNo            0
    AbrtCd            1  <--went past the Abort Time 13Dec07 1400Z
```

```
M.ission
   FPchks          5
   dBarGo        490
    Fall0         15
    Ztar0        500
   Tlast0          0
    Rise0         83
   MxPsec       1800
     dTdZ         26
   mxSeek         60
   SAMmin          1
     Nsam         60
   Surfmn       1440
    XAchk        960
   FnlDiv          1
   AbrtYr          7   <--abort 13Dec07 1400Z
   AbrtMo         12      which is 9667 secs after StartMission
   AbrtDa         13
   AbrtHr         14
   AbrtMn          0
   EEP>
   v
   OK EEPROM checksum
```

The piston was retracted to the full IN position and this took 857 seconds at pump battery =13.85V and pump current =153 mA.

The Flash memory with a record of what happened during the dive was dumped. Only selected portions of the 63106 bytes of data are shown below:

```
StartMission 13Dec07 111853Z= 250859933 secs
F      8  -0.0  <--F=falling, 2nd col =seconds, 3rd=dBar
F     13  -0.0
F     18  -0.0
F     23  -0.0
F     28  -0.0
F     33  -2.6
F     38  -0.0
F     43  -0.0
F     48  -0.0
F     53  -0.1
F     58  -2.8
F     63  -1.9
F     68  -0.0
F     73  -0.0
F     78  -0.1
F     83  -2.1
F     88  -2.1
F     93  -0.0
F     98  -0.0
F    103  -0.0
F    108  -0.1
F    113  -2.2
F    118  -2.2
F    123  -0.0
F    128  -0.0
F    133  -0.1
F    138  -2.2
F    143  -2.1
F    148  -1.1
```

```
F     153  -0.1
F     158  -0.1
F     163  -0.0
F     168  -2.6
F     173  -0.0
F     178  -0.1
F     183  -0.0
F     188  -0.0
F     193  -0.0
F     198  -3.1
F     203  -0.0
F     208  -0.0
F     213   0.7
F     218   3.2   <--in the water after 218secs
                    Av fall = 63c/s with 7.8kg depressor wt
F     293  50.7
. . .             Av fall = 65c/s
F     373 102.9
. . .             Av fall = 64c/s
F     448 150.9
. . .             Av fall = 64c/s
F     528 201.8
. . .             Av fall = 64c/s
F     608 252.9
. . .             Av fall = 65c/s
F     683 301.3
. . .             Av fall = 64c/s
F     763 352.7
. . .             Av fall = 64c/s
F     818 388.1   <--depressor wt jettisoned
. . .             Av fall = 25c/s
F     838 393.1
. . .             Av fall = 7.8c/s
F     898 397.8
F     903 398.1   <--Fall0 time=15min=900secs was passed
D     919 399.0    6.884 34.166   0  <--Drifting, secs,dBar,T,S,pumpsecs
. . .             Av fall = 7.3c/s
D    1689 454.9    6.405 34.187   0
. . .             Av fall = 8.2c/s
D    2249 500.9    6.023 34.228   0
D    2319 506.3    5.942 34.228   0  <--1st pump OUT for 1 second
D    2397 512.1    5.906 34.230   1
D    2479 518.1    5.885 34.233   5
D    2561 523.7    5.862 34.233   9
D    2646 529.6    5.840 34.235  16
D    2731 536.1    5.812 34.236  23
D    2817 543.1    5.781 34.238  32
D    2907 549.5    5.738 34.243  44
D    2997 554.9    5.686 34.248  56
D    3088 559.7    5.641 34.251  70
D    3182 566.3    5.579 34.252  85
D    3276 572.9    5.534 34.259 102
D    3373 578.5    5.542 34.259 120
D    3471 585.2    5.530 34.261 140
D    3570 591.9    5.504 34.265 162
D    3672 599.1    5.491 34.264 185
D    3775 605.4    5.470 34.266 210
D    3878 611.8    5.468 34.266 237
D    3985 614.5    5.445 34.270 267
```

```
D   4094 615.9   5.447 34.268 297
D   4202 616.3   5.445 34.269 327
D   4310 619.8   5.452 34.268 357
D   4418 625.4   5.448 34.269 389
D   4530 629.9   5.437 34.271 422
D   4641 632.6   5.407 34.271 455
D   4753 634.1   5.401 34.275 490  <--neutral,OUT=525secs
D   4865 631.9   5.409 34.272 525
D   4977 627.7   5.360 34.280 560
D   5088 624.5   5.369 34.276 593
D   5199 617.1   5.369 34.276 626
D   5307 612.5   5.327 34.282 656
D   5415 605.8   5.339 34.279 686
D   5519 600.1   5.337 34.279 713
D   5623 592.9   5.315 34.281 738
D   5725 585.6   5.368 34.275 763
D   5825 577.1   5.439 34.266 785
D   5923 567.5   5.448 34.270 805
D   6018 557.2   5.470 34.264 822
D   6108 546.8   5.476 34.265 836
D   6198 537.8   5.489 34.262 848
D   6281 527.5   5.489 34.262 858  <--piston at max OUT
P 507.8   5.584 34.254  SBE dBar,T,S reading every 2 seconds
. . . delete 299scans gap=600secs Av rise = 4.9 c/s
P 478.7   6.145 34.211
. . . delete 299scans gap=600secs Av rise = 6.7 c/s
P 438.7   6.384 34.186
. . . delete 299scans gap=600secs Av rise = 4.5 c/s
P 411.7   6.627 34.168
. . . delete 299scans gap=600secs Av rise = 6.8 c/s
P 371.0   6.983 34.160
. . . delete 299scans gap=600secs Av rise = 4.1 c/s
P 346.4   7.306 34.142
. . . delete 299scans gap=600secs Av rise = 5.7 c/s
P 312.4   7.431 34.128
. . . delete 299scans gap=600secs Av rise = 4.6 c/s
P 284.9   8.057 34.083
. . . delete 49scans  gap=100secs  Av rise = 4.7 c/s
P 280.2   8.100 34.077
. . . delete  9scans  gap=20secs   Av rise = 4.5 c/s
P 279.3   8.106 34.077
. . . delete  9scans  gap=20secs   Av rise = 4.5 c/s
P 278.4   8.111 34.076
                  Average ascent velocity from 507.8 dBar to 278.4 dBar
                  in 4340 s = 5.3 c/s.  Effective CdA => 53 gms buoyancy
P 278.3   8.111 34.076
P 278.2   8.111 34.076
P 278.1   8.111 34.076  <--ROV grabbed SOLO near this depth
P 277.9   8.113 34.076
. . . delete 179scans  gap=360secs  Av rise = 14 c/s
P 227.2   8.645 34.018
. . . delete 59scans  gap= 120secs  Av rise = -0.9 c/s
P 228.3   8.673 34.014
P 228.3   8.676 34.014  <--SBE stopped after 2416 scans = 4832 seconds.
                        Rise0=83 minutes=4980 secs; the difference=148
                        secs. During rise, SOLO checks every 200 secs.
                        SOLO stopped the profile because Rise0 had
                        expired.
```

Estimation of Drag Coefficient

The "F" data taken while SOLO was falling with the big descent weight can be used to estimate the drag coefficient. We assume that the SOLO, with all of the funnels, was close to neutrally buoyant at the surface and that only the descent weight provides the force to make the instrument sink. SOLO and the funnels can't be more than 200 grams heavier than neutral or the instrument will never surface. As this is small compared to the 7.8 kg descent weight, we assume that the drag at terminal velocity is 7.8 kg.

At 293 seconds after the start of the mission, SOLO was at 50.7 dBars. At 818 seconds after start, the descent weight was still attached and SOLO was at 388.1 dBars. The average terminal velocity v is v=(388.1-50.7 dBar)/(818-293 seconds) = .64 dBar/second = 64 cm/sec.

drag = CdA * (v*v) where CdA is the effective drag coefficient.

From the data we compute CdA=1.90 g/((cm/s)^2)

$\frac{.99}{cm/}$

For comparison, the effective CdA of a standard SOLO with its damping disk is 0.5. The approximate projected area of the LST configuration is 759 in^2 while the standard SOLO projects 154 in^2:

LST area/SOLO area = 4.9
LST CdA/ SOLO CdA = 3.8

Ballasting SOLO with in situ data

The "D" data taken while SOLO was falling and attempting to hit the target depth of 500 dBar can be used to ballast SOLO. After the descent weight was dropped SOLO continued to fall. It periodically checked the pressure against its specified target pressure of 500 dBar and began to move the hydraulic piston to try to get closer to the target. SOLO is neutrally buoyant at the maximum depth where it turns around and begins to ascend. SOLO turned around at a depth of 634 dBar at 4753 seconds past the start of the mission. At this point the SeaBird indicated the temperature was 5.40 degC and the salinity was 34.275 psu.

The "D" listing indicates that the piston had been moved OUT for 525 seconds before SOLO turned around. The full stroke of the piston delivers 210 grams of buoyancy so in 525 seconds, the piston would have moved to create (525 s)/(858 s) * 210 grams = 128 grams of buoyancy. This means that a SOLO with its piston fully retracted is negatively buoyant by 128 grams at 634 dBar, 5.40 degC, and 34.275 psu.

The LST instrument has a net air weight of 45.4 kg. This does not include the weight of the descent weight. If we assume that the assembly is close to neutrally buoyant in sea water we can estimate the displaced volume of the assembly to be 45400 grams/(1.025 g/cm^3) = 44300 cm^3. The SOLO hull has a displacement of 29500 cm^3 so the net volume of all the of added LST components is 14800 cm^3.

The LST components are primarily plastic and I arbitrarily guessed that the LST is 25% LDPE, 25% UHMW, and 50% PVC.

Material	Bulk Modulus (GPa)	Compressibility(/dBar)	Volume(cm^3)
LDPE	4.05e9	2.47e-6	3700
UHMW	4.11e9	2.43e-6	3700
PVC	5.50e9	1.82e-6	7400
SOLO		2.205e-6	29500

The average compressibility weighted by volume is then 2.2e-6/dBar, insignificantly different from the compressibility of SOLO. Note however, that the volume of LST is 44300 cm^3 or 1.5 times that of a standard SOLO.

Two MATLAB scripts allow the buoyancy of LST to be estimated under various oceanic conditions. The first script computes the density of seawater from pressure, temperature, and salinity.

```
function r0 = density(t,s,p)
%function r0 = density(t,s,p)
% computes density in sigma units given
%      t = degrees celsius
%      s = psu
%      p = decibars
% from UNESCO 1980 eqn. of state

    t2 = t.*t;
    t3 = t2.*t;
    t4 = t3.*t;
    t5 = t4.*t;

    s15 = s.^(1.5);
    s2 = s.*s;
     p = p/10;   % now in bars
    p2 = p.*p;
%---------------------------------------------------------------------
% EACH COLUMN CONTAINS COEFFICIENTS OF 1, T, T**2, T**3, T**4, T**5;
% EACH ROW CONTAINS COEFFICIENTS OF:
%              1          S         S**3/2       S**2
%---------------------------------------------------------------------
    sigt1=   -0.157406    +8.24493e-1*s  -5.72466e-3*s15 +4.8314e-4*s2 ...
       + t.*( 6.793952e-2  -4.0899e-3*s  +1.0227e-4*s15);
    sigt2= t2.*(-9.095290e-3  +7.6438e-5*s  -1.6546e-6*s15)  ...
        +t3.*( 1.001685e-4  -8.2467e-7*s);
    sigt3= t4.*(-1.120083e-6  +5.3875e-9*s) +t5.*( 6.536332e-9);
sigt = sigt1 + sigt2 + sigt3;

    cko=      1.965221e+4  +5.46746e+1*s  +7.944e-2 *s15    ...
       + t.*( 1.484206e+2  -6.03459e-1*s  +1.6483e-2*s15);
    ck1 =t2.*(-2.327105e0   +1.09987e-2*s  -5.3009e-4*s15)  ...
       +t3.*( 1.360477e-2  -6.1670e-5 *s) +t4*(-5.155288e-5);
cko = cko + ck1;

    ckp=  p.*(3.239908      +2.2838E-3*s  +1.91075E-4*s15   ...
       + t.*(1.43713E-3   -1.0981E-5*s)                ...
       +t2.*(1.16092E-4    -1.6078E-6*s)               ...
       +t3.*(-5.77905E-7));

    ckp2=p2.*(8.50935e-5    -9.9348e-7*s      ...
       + t.*(-6.12293e-6  +2.0816e-8 *s)     ...
       +t2.*(5.2787e-8    +9.1697e-10*s));
ck = cko + ckp + ckp2;
%
% NOW EVALUATE RO(P)= RO(0)/(1-P/CK),
% AND RO= 1000.+SIGT IN KG/M**3.
%
    r0=(1000.+sigt)./(1.-p./ck);
    r0=r0-1000;
```

The second script computes the buoyancy of the LST assembly

```
function [buoy,vol,rho] = LSTballast(dBar,degC,S)
%computes LST buoyancy at P,T,S
%buoy = LSTballast(dbar,degC,s)
% dBar = pressure (decibars)
% degC = temperature (degC)
% S = Salinity (psu)

%Values pertinent to LST Dec2007
alpha=2.2e-6; % alpha = pressure coeff of LST (1/dbar) typ 2.2e-6
beta = 6.9e-5; % beta = temp coeff of SOLO (1/degC) typ. 6.9e-5
airwt = 45.4e3;  % airwt = air weight of SOLO in grams
%SOLO description
m0=airwt;  %estimate mass from air wt
v0= m0/1.025;  %guess volume from mass and typ. water density=1.025
mcorr=301;  % grams mass correction determined from Dive 2 in situ ballasting
        % to be neutral @ 634dBar,5.40C,24.275psu with 128gms pumped OUT

rho= ( 1 +  density(degC,S,dBar)/1000);   %water density
vol=v0*(1 - alpha*dBar + beta*degC);  %SOLO volume cm^3

buoy=vol.*rho-(m0+mcorr);%net buoy of SOLO with piston IN.
```

The in situ data from Dive 2 have been used to adjust mcorr so that the script correctly predicts the buoyancy observed at the turning depth. Note that LSTballast computes the buoyancy of the LST assembly when the SOLO piston is fully retracted.

Discussion of the ballasting

The sensitivity of LST buoyancy to changes in pressure, temperature, or salinity can be explored by playing with these scripts. In summary, for conditions around 500 dBar, 6 degC, and 34.2 psu, the sensitivities are:

10.2 gram / 100 dBar
34.8 gram / psu
-3.2 gram / degC

This means that if LST is at 600 dBar and we want to come up to 500 dBar that SOLO has to pump OUT to increase the displacement by 10.2 grams. The typical pumping rate of SOLO is .25 gram per second. Thus to increase the displacement by 10.2 grams to rise by 100 dBar, the pump has to run for 40.8 seconds. The SOLO EEPROM parameter **dTdZ** is used to convert pressure errors to pump time. The value used in the December test was **dTdZ**=26 while a more appropriate value would have been **dTdZ**=41. Using the smaller value means that the seeking algorithm will always underestimate the size of the correction and will take longer to converge on the target depth. In the future, the value of **dTdZ** should be 41.

The sensitivity of the net buoyancy to the water temperature and salinity can have disastrous consequences. For example, from Dive 1 in the December 2007 test we have a CTD reading at the surface of T=11.3 degC and S=33.38 psu. The computed buoyancy of LST under these conditions is -245 grams with the piston fully retracted. But the maximum buoyancy obtainable from the piston is 210 grams so even with the piston fully extended, the net buoyancy of LST at the surface is -35 grams. Under these conditions, LST will not be able to surface unless some weight is dropped to reduce the mass. One should note the large sensitivity to salinity. In areas where the surface salinity is very low. LST might not be able to surface.

We apply the ballasting scripts to several cases of interest:

P = 0 dBar T=20 degC S=34.800 (MBARI ballasting tank)
buoyancy = -255 grams

P = 500 dBar T=6.02 degC S=34.29 (Actual Dive 2 @ 500 dBar target)
buoyancy = -144 grams

This implies that if you can remove all of the air bubbles and ballast LST to weigh 111 grams in the ballasting tank, then it will be neutrally buoyant at the target conditions with the piston fully retracted. In this case, SOLO could not retract the piston to correct for the situation where the actual water at the target is more dense than we had expected so LST would hover at too shallow a depth. It is advisable to ballast so LST is somewhat negatively buoyant at the target depth and conditions; then SOLO can correct in either direction. If one ballasts to have LST weigh 50 grams at the target with the piston retracted, we have 160 grams of buoyancy to get back to the surface with a fully extended piston. The ballasting sensitivities given above mean that the salinity can be higher by 1.5 psu or colder by 15 degC than expected and LST could still reach the target depth and be neutrally buoyant with the piston retracted. If the water conditions are as expected, the extra 50 grams means LST would be neutrally buoyant at 50gms/(10.2gm/100dBar)=490 dBar deeper than the target and would stop at 990 dBar.

The average ascent speed during the CTD profile is 5.3 c/s from 507 to 278 dBar. Using the drag coefficient estimated from the falling velocity, we compute that the drag on LST during the ascent is 53 grams. This implies that the net buoyancy of LST is 53 grams with the piston all the way OUT. If LST is buoyant by -144 grams at the 500 dBar target (with the piston IN) and we move the piston out its maximum of 210 grams, we compute that the LST should be positively buoyant by -144 + 210 = 66 grams with the piston OUT. The consistency between these buoyancy estimates is far better than expected.

What went wrong in Dive 2?

1. **Fall0** too short
2. **dTdZ** too small
3. Drifting phase too short. Seeking algorithm didn't allow sufficient time for corrections to take effect.
4. **Rise0** time too short to reach the surface
5. The ballasting and water column stratification are such that LST would not have surfaced without the aid of the ROV or by dropping the ascent weight.