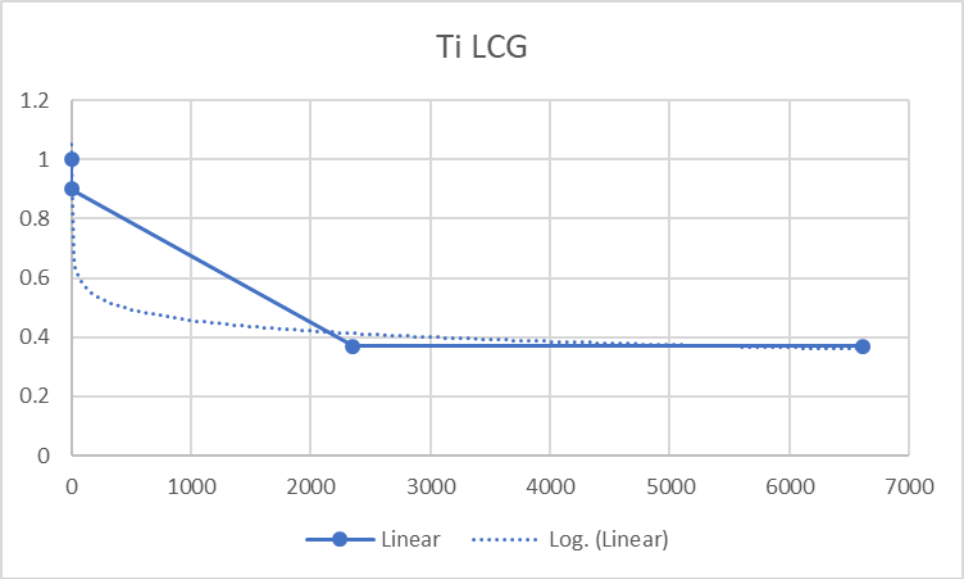
Revised Versions of Ti-64 and Al-2024 Incorporating Natural Log Tables

New Versions

- Conclusions presented at the August 14, 2019 were double-checked and confirmed
  - LCINT doesn't influence TABLE input
  - LCINT should be set higher than default for plasticity algorithm convergence
    - LCINT=1000 was recommended by DYNAMORE and seems to work fine
- LCINT can be set on each individual *DEFINE_CURVE card
  - *CONTROL_SOLUTION is not required
  - Setting LCINT on the *DEFINE_CURVE for stress-strain curves will minimize the chance of users not using the recommended value
- CK is finishing up with the Al-2024 V2-2 models
  - Due to high number of curves used in the V2-1 models, no change in behavior is expected
- With the Ti-64 models, some change is expected
  - An issue has been noted, as described in the following

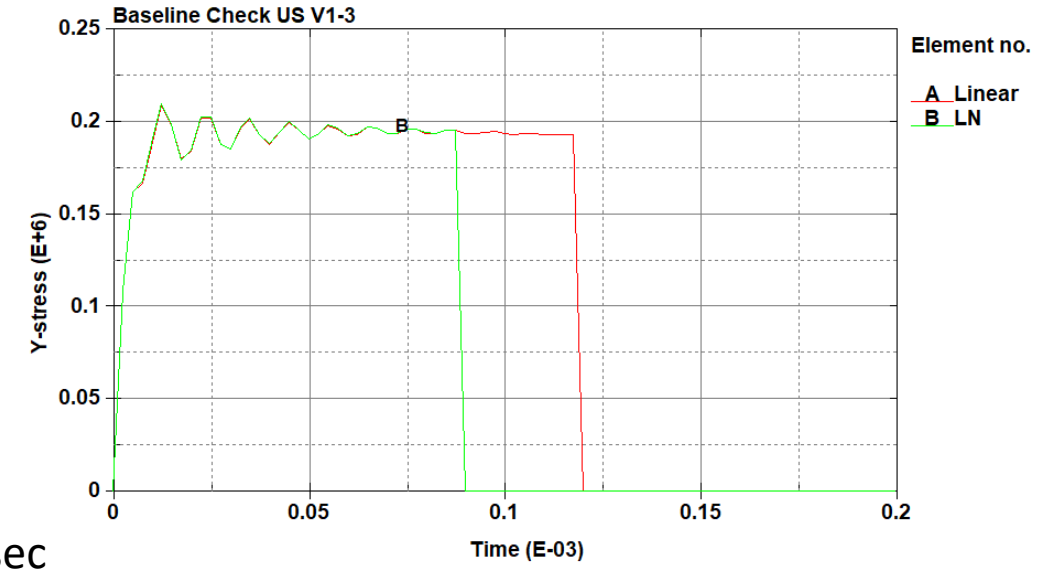
Ti-64 LCG Curve

- LCG curve scales the failure strain on the basis of strain rate
- For Ti-64 four test data points were used to create the scaling curve
- A large difference between Natural Log interpolation and Linear interpolation is occurring
  - The Excel trendline below is just for illustration
  - The LS-DYNA LN interpolation goes thru the data points

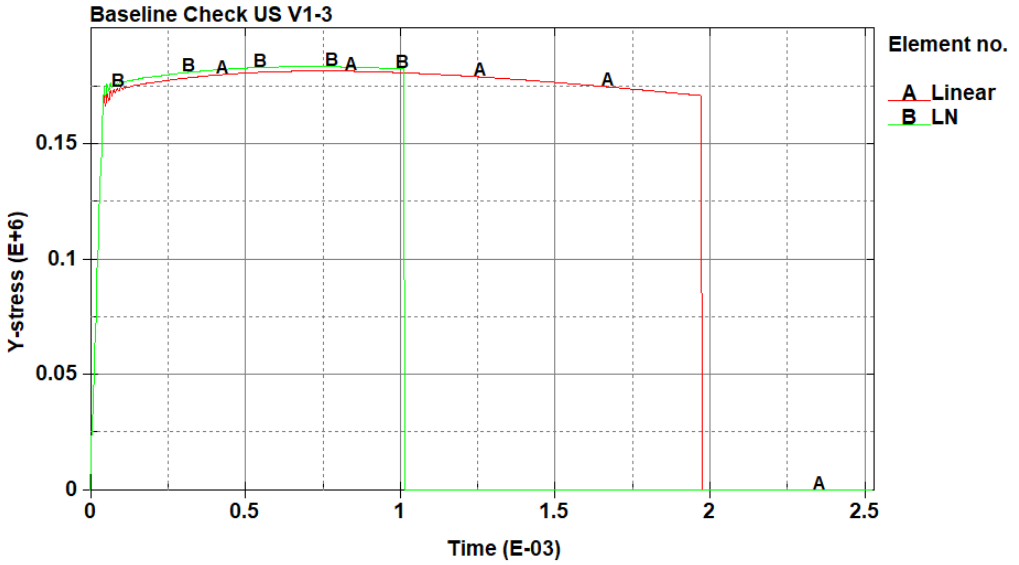


Element Failure Comparison

- Results consistent with previous chart
- Large difference in results at strain rates below 2000 1/sec



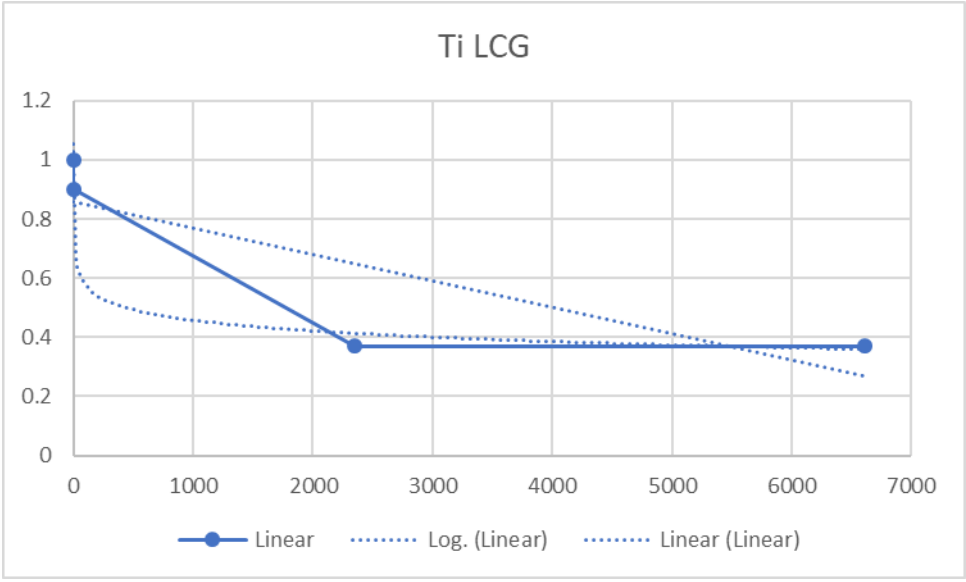
2000 1/sec



250 1/sec

What to do?

- Test behavior of Ti-64 seems to follow Natural Log trend
  - Linear trendline below is just for illustration of global trend
  - LS-DYNA interpolation follows solid line
- BUT, using the LN format for LCG will lead to large difference in failure strains at some strain rates
- So, what to do?
  - Released Al-2024 model uses LN LCG curve



Comparison of Standard and Natural Log Stress-Strain Table Input, LCG Input and LCINT

August 14, 2019

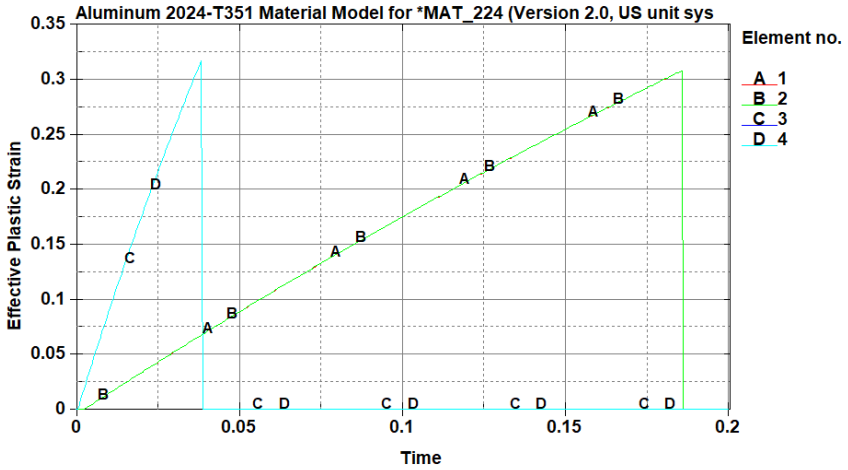
Behavior using Different Input Forms was Investigated

- Single solid elements, under uniaxial tension, at several rates were compared
- LCINT appears to have absolutely no effect on *DEFINE_TABLE part of the input
  - No re-discretization of table strain rate discretization appears to be occurring
  - When LCINT=100, plasticity algorithm doesn't always converge
- Al2024 V2.1 uses standard (linear) input with 260 different rates being defined for LCK1 (260 stress-strain curves being referenced)
  - The results between natural logarithmic input and linear input are identical in all the cases I tried
  - An "extreme" model, using only two stress-strain curves, was created to test LS-DYNA function
- Ti64 V1.2 uses linear input with 15 different rates being defined for LCK1 (15 stress-strain curves being referenced)
  - Here, there is a difference (improvement) using the natural logarithmic input option
- Both the Al2024 and Ti64 released models use linear input for LCG (LCG scales failure strain for rate)
  - Natural logarithmic input now available
  - *DEFINE_CURVE is used, so higher LCINT could improve accuracy, when linear input is used

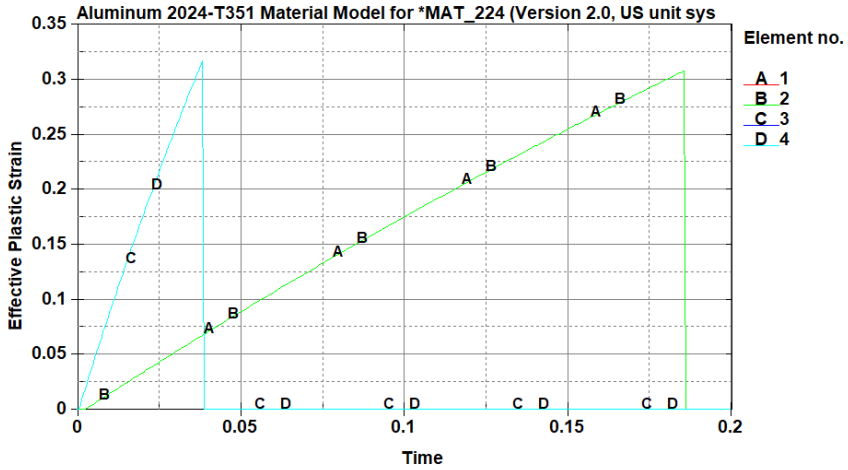
Aluminum 2024 V2.1

- Many rates, with several loadings, were considered
- Results between standard, linear *DEFINE_TABLE input and natural log option were always identical
  - Recall 260 stress-strain tables are used in the input
- Varying LCINT had no effect

LCINT = 100

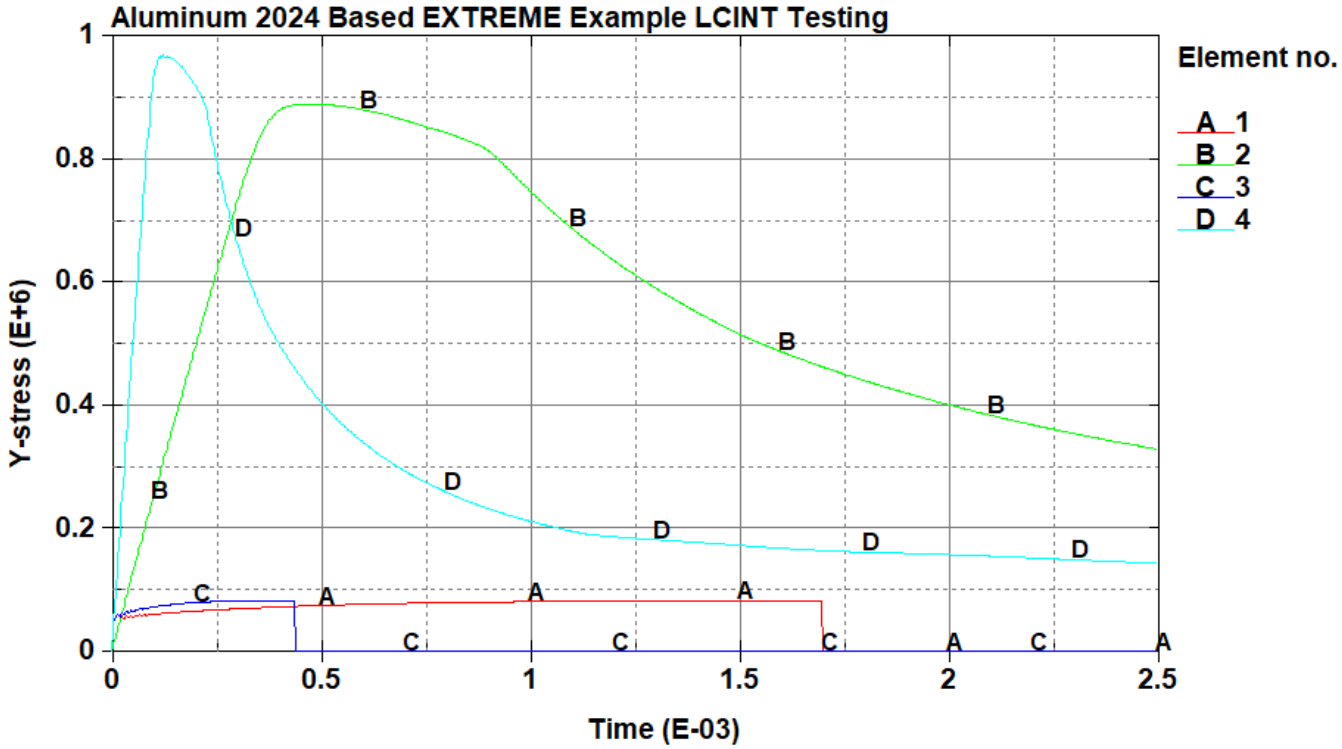


LCINT = 1E5



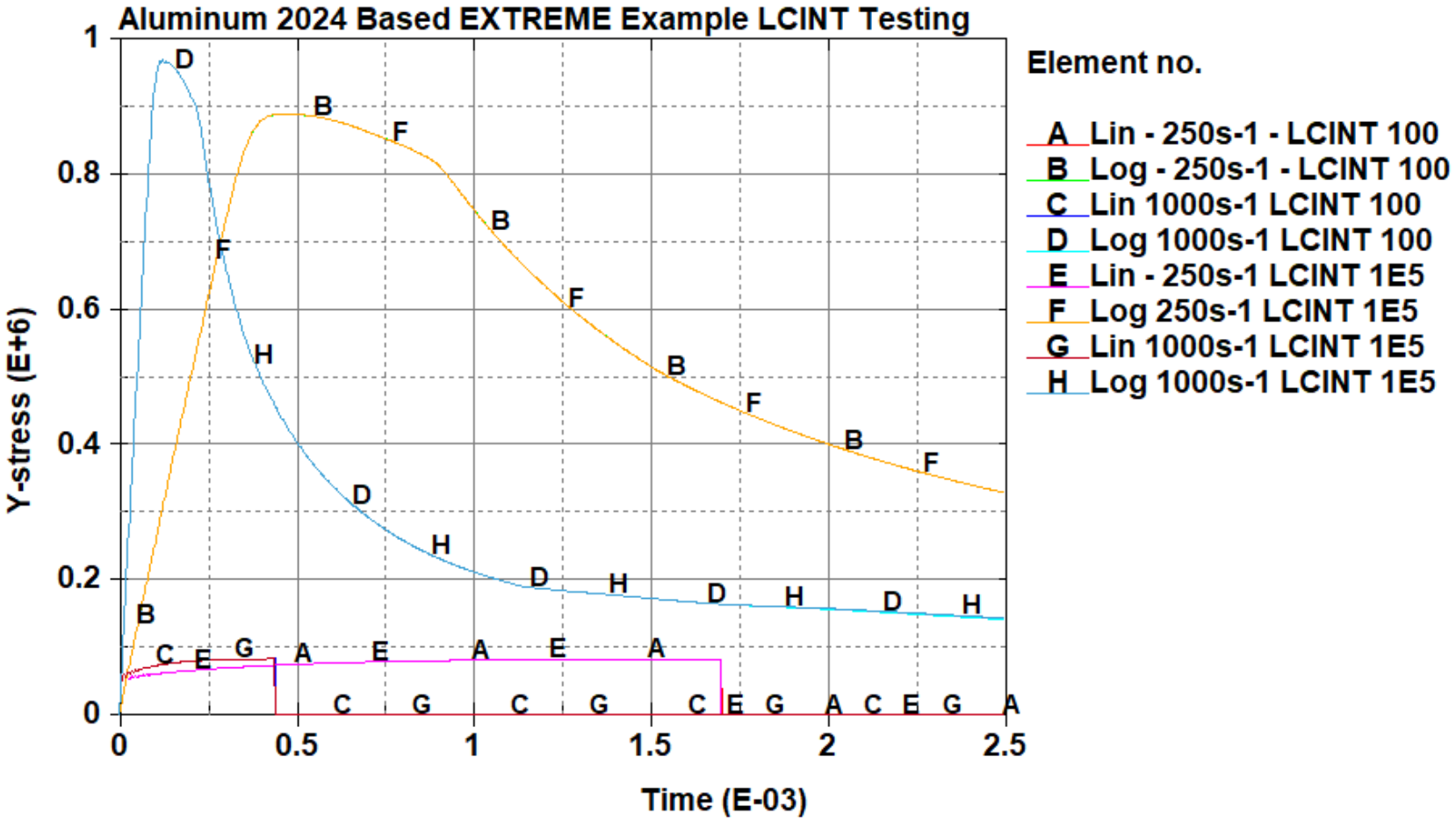
“Extreme” Modified Al2024 Model

- A model was created to test LS-DYNA table, curve and LCINT functioning
  - Only two stress-strain curves included, the lowest and highest
  - Now there is a huge difference between standard, linear input and natural log input
    - A and C are standard linear input, at 250 s-1 and 1000 s-1
    - B and D are natural log input, at 250 s-1 and 1000 s-1
    - So compare A and B; C and D



“Extreme” Modified Al2024 Model

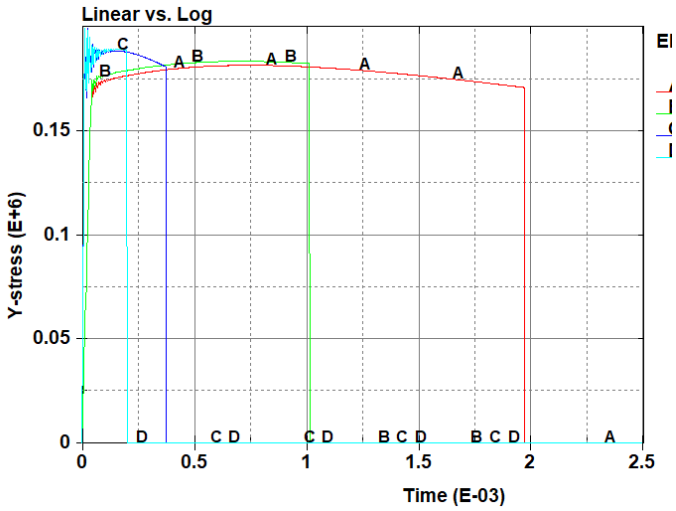
- But varying LCINT had absolutely no effect on the results



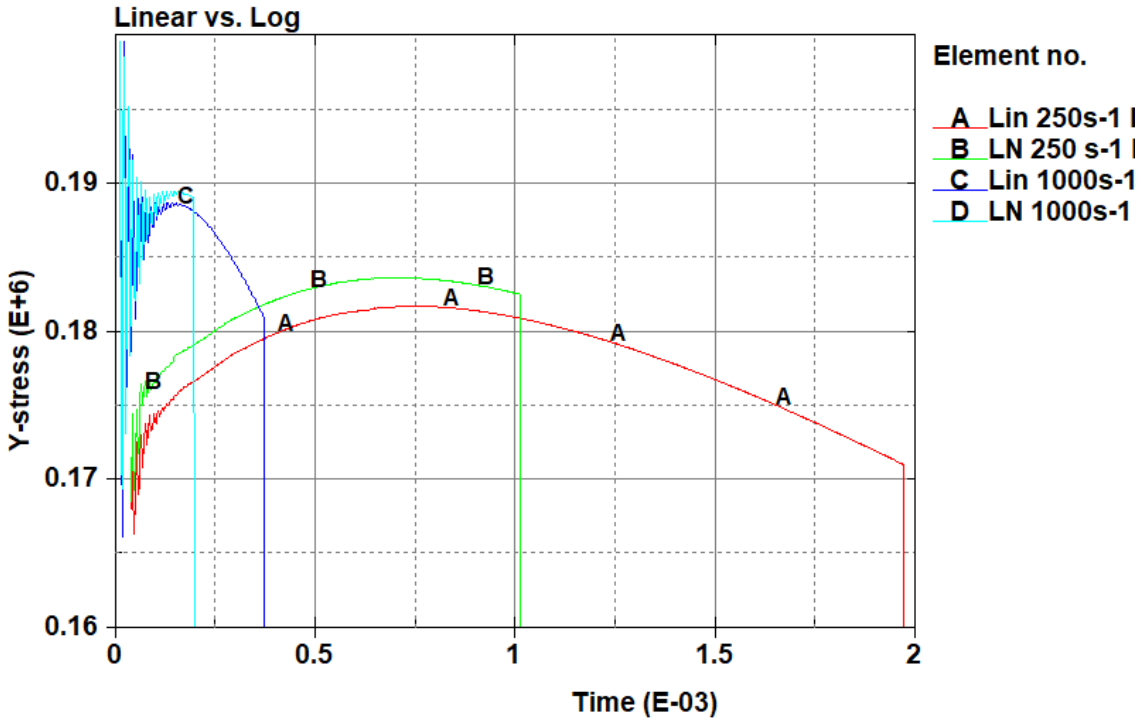
Conclusions Checked with Ti-64 Model

- With only 15 stress-strain curves, there is a difference between linear and natural log input in the Ti-64 model
  - Here, LCINT=100 is used

Full Result

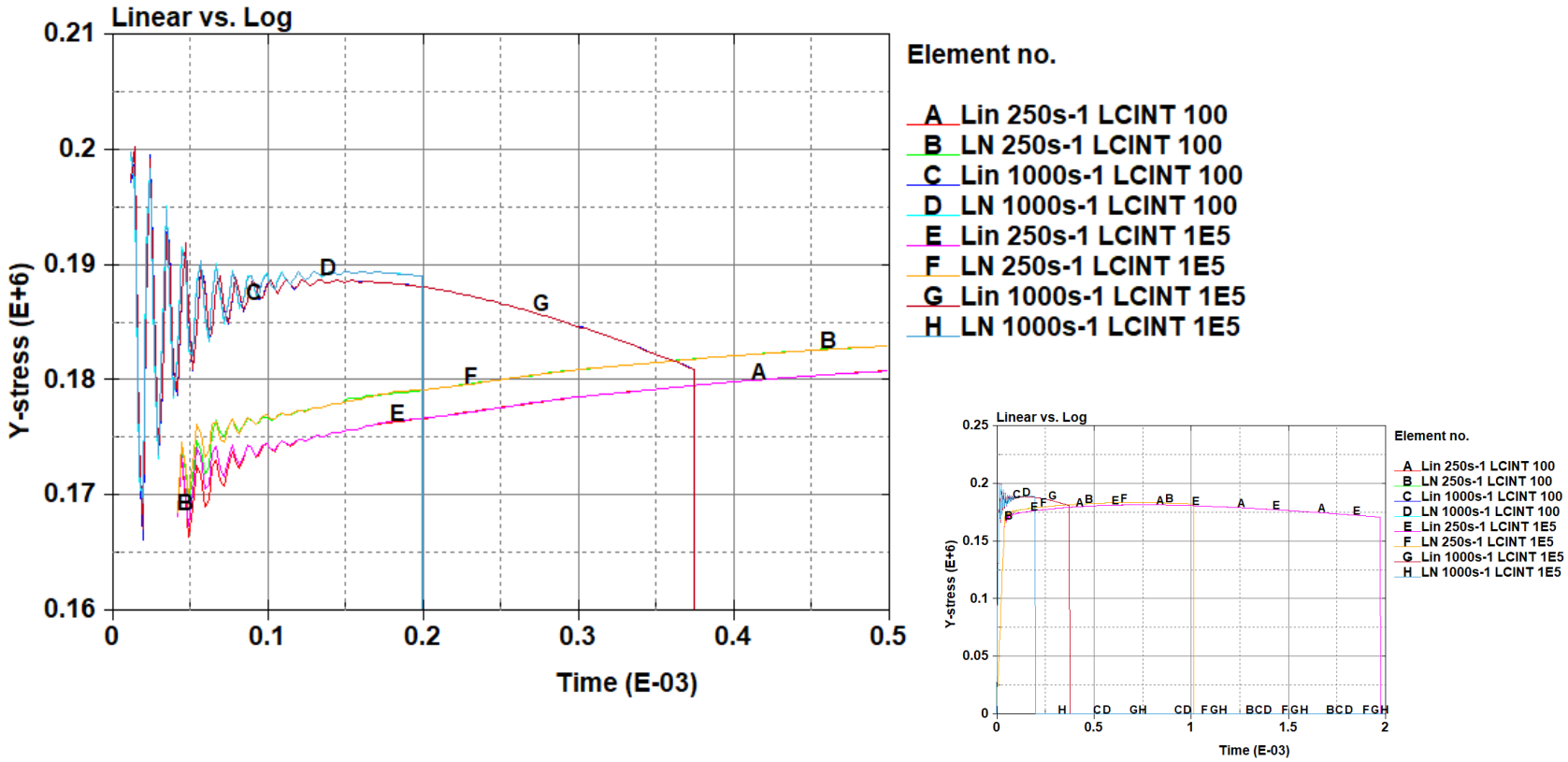


Closeup

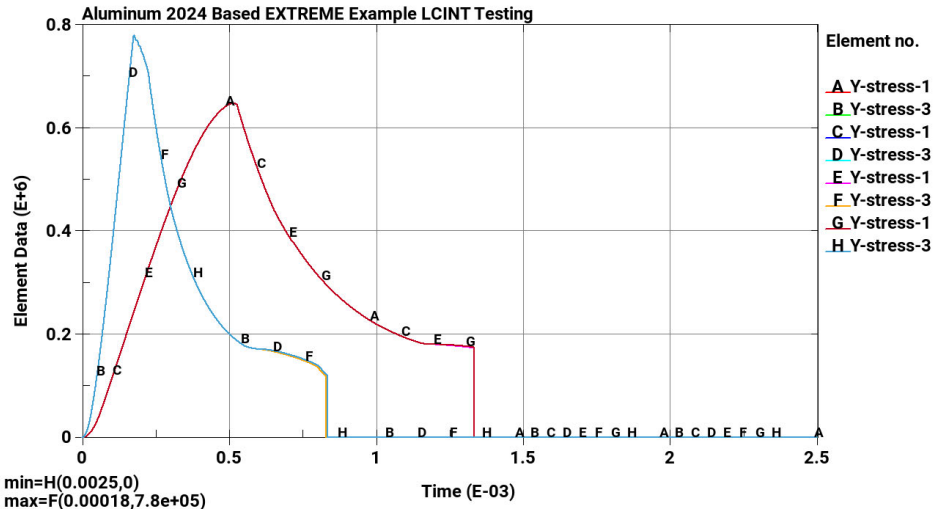


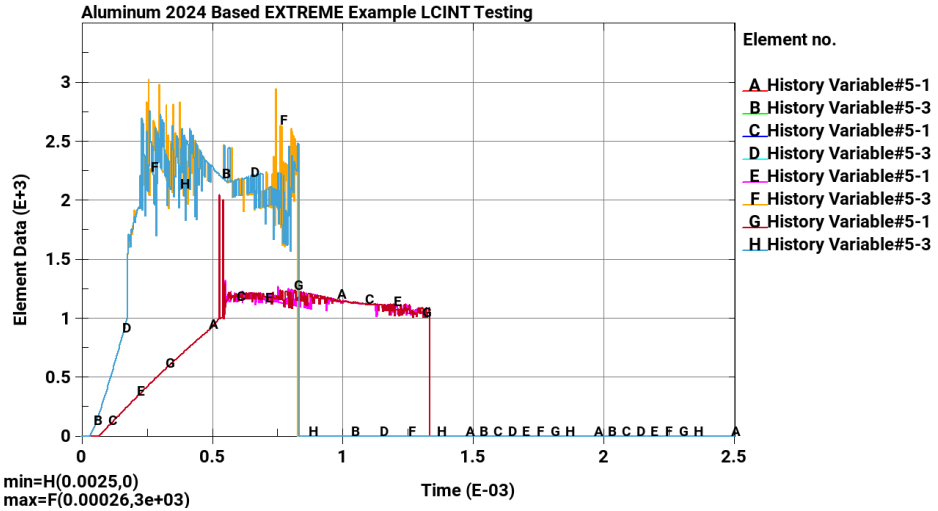
Conclusions Checked with Ti-64 Model

- Once again, varying LCINT made no difference to strain rate discretization
  - Here evidence of non-convergence with LCINT=100 can be seen in the oscillations, if you look closely enough



CK's Double-Checking

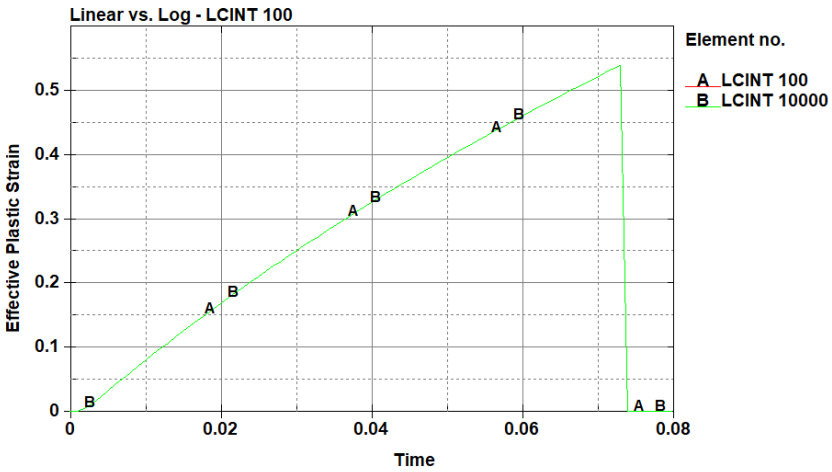


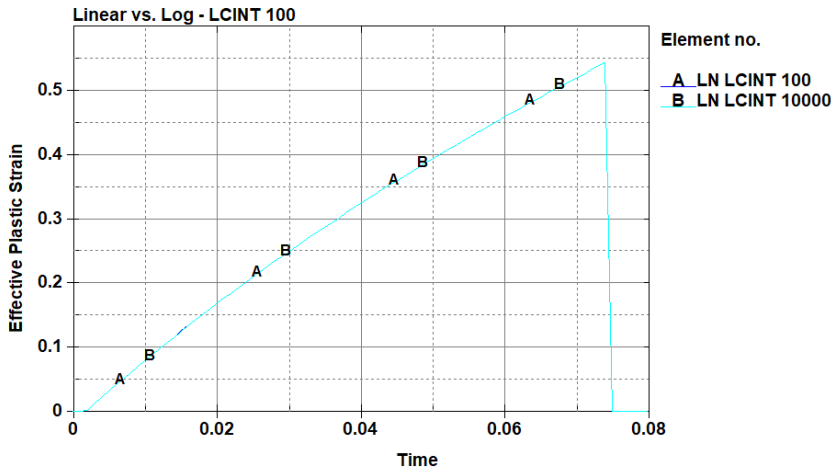


- A third strain rate curve was added to the "extreme" example
  - Curves were defined at the lowest and highest rates as before, and an intermediate rate at 1000 s-1 was added
- The loading was modified by prescribing acceleration rather than velocity
  - As before, two different rates were used
- LCINT was set to 10, 50, 100, and 200
  - Only the results from the linear input are shown
  - LCINT had no effect on the results

Paul Requested Another Check Case

- Solid elements loaded at 10 s-1
- Material model with curves defined at rates of ~0 s-1, 10 s-1, and 10000 s-1
  - Magnitude at 10 s-1 and 10000 s-1 2X of ~0 s-1
  - Stress-strain curves are flat (elastic-plastic)
- Runs were performed with LCINT=100 and LCINT=10000
  - Results are essentially identical
    - LCINT has no affect on *DEFINE_TABLE discretization
  - As previously, with LCINT=100, plasticity algorithm doesn't always converge





Recommendations and Comments

- For consistency and some improvements in accuracy, both the Al2024 model and the Ti64 model should be converted to natural log input
  - For both LCK1 and LCG
- LCINT should be set higher than 100 for plasticity algorithm convergence
  - DYNAMORE recommended 1000
    - 1000 may be higher than needed, but 1000 seems to not slow run times down noticeably
- LCINT can be set on the *DEFINE_CURVE card
  - This is much less likely to be modified by users than including or not including a *CONTROL_SOLUTION card
- Set LCINT=1000 on each *DEFINE_CURVE
  - There are hundreds of curves, so don't do this using an editor!
- On material models for which the natural log option is not currently available (GYS and MAT264), using a high number of stress-strain curves will give the same accuracy