

Alliance for the Development of
ADDITIVE PROCESSING
Technologies

Effect of Defects and the Steps
to Improve Non-Destructive
Evaluation of Additively
Manufactured Parts and
Materials

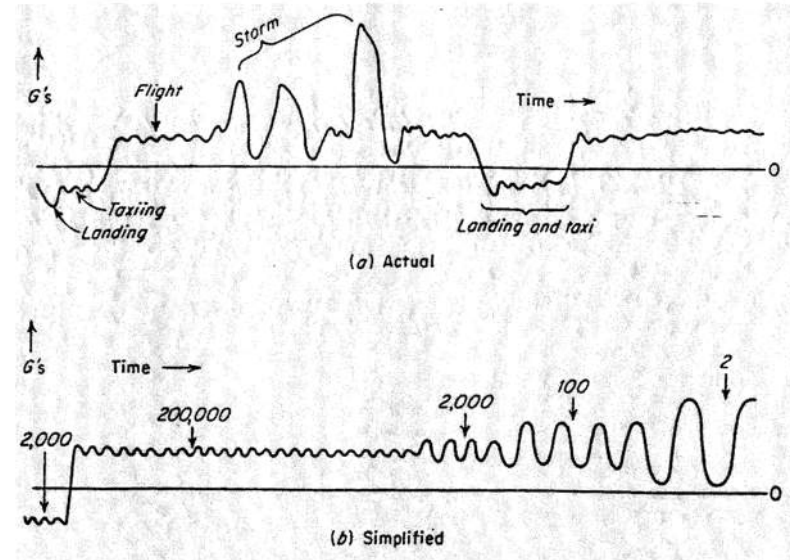
**OPTIMIZE FOR
ADDITIVESM**

processes • materials • parts



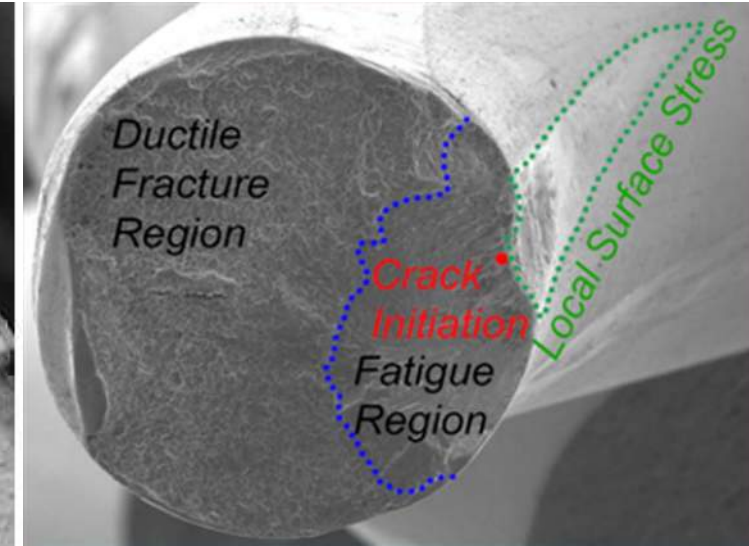
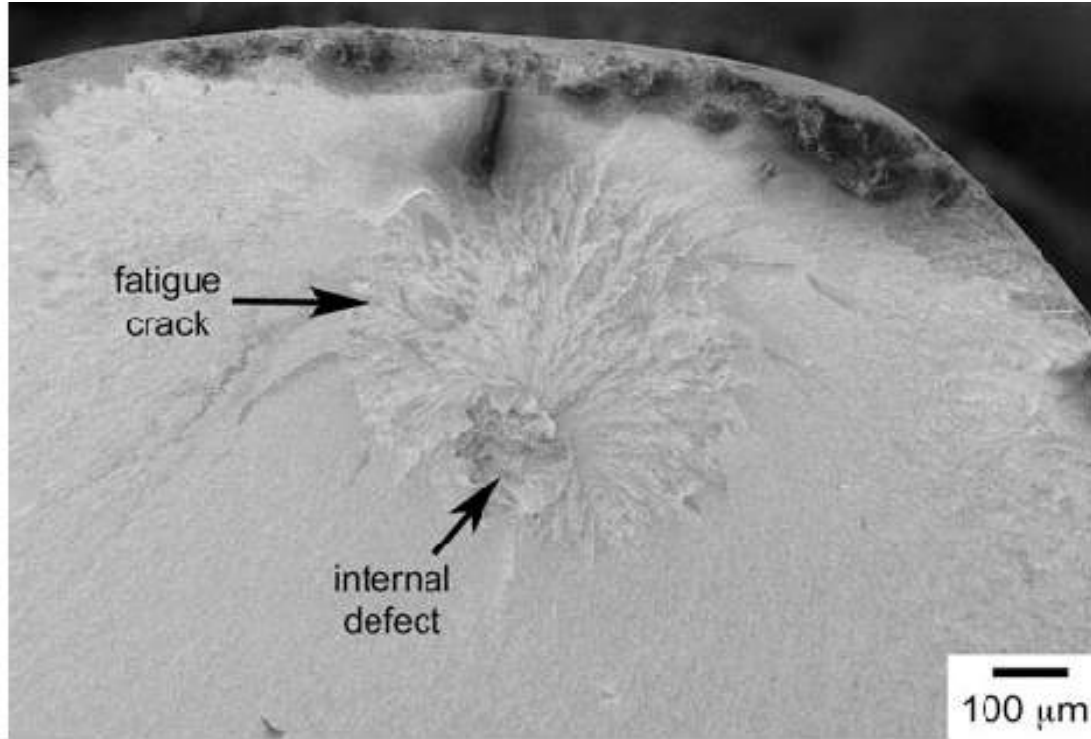
Background on the Effects of Defects STTR

- The potential for rapid, flexible part development is well established.
- Concerns have started to move beyond “Is this a good idea”
- “How do we know AM parts are reliable for [insert application].”



From
N.E. Dowling
“Mechanical
Behavior of
Materials,”
Prentice Hall,
Inc.,
1993, p. 351.

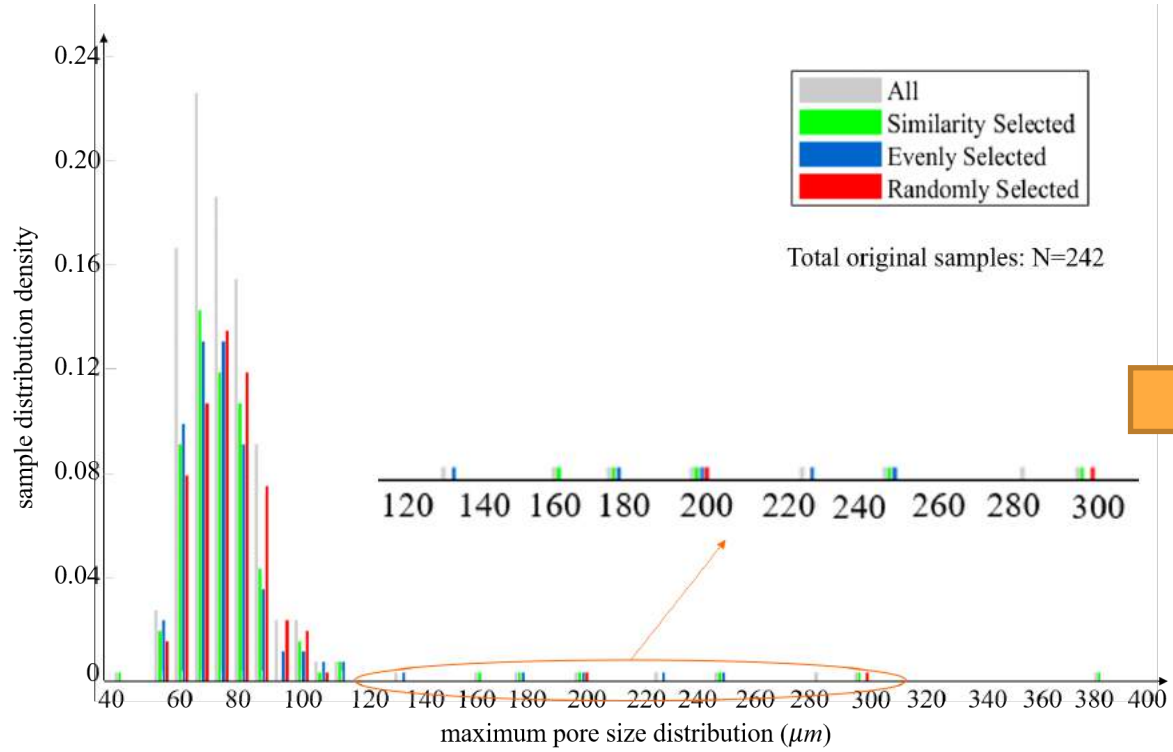
Part performance controlled by rare defects



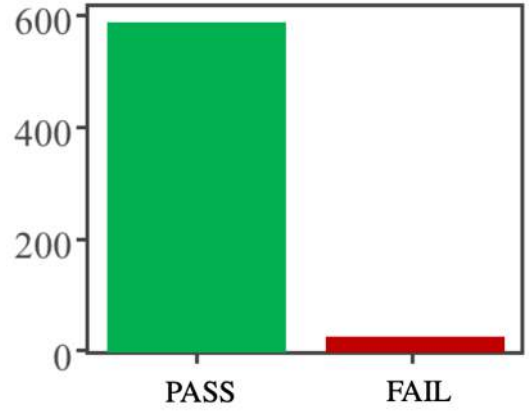
(left) Kruzic, Jamie. (2010). Metallurgical and Materials Transactions A. 42. 1516-1523. 10.1007/s11661-010-0413-1.

(right) Muhammad M Sherif and Osman E Ozbulut 2018 Smart Mater. Struct. 27 015007

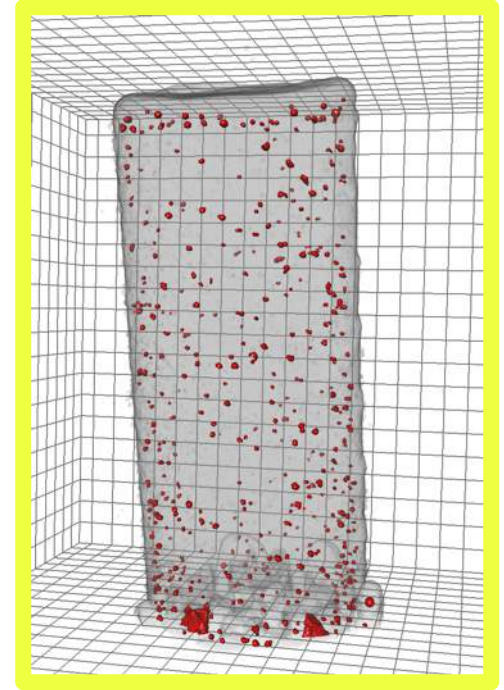
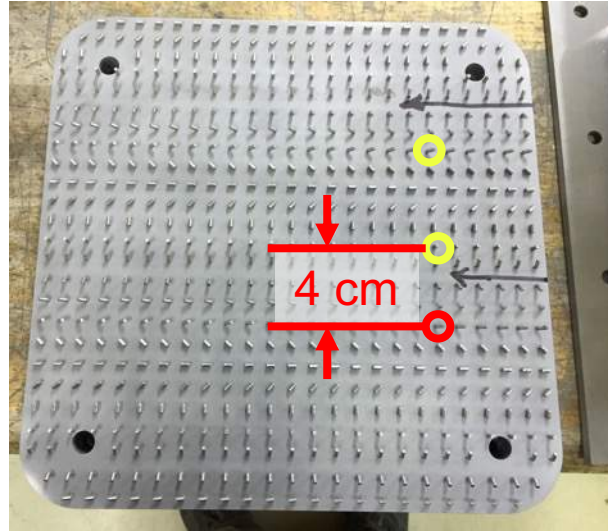
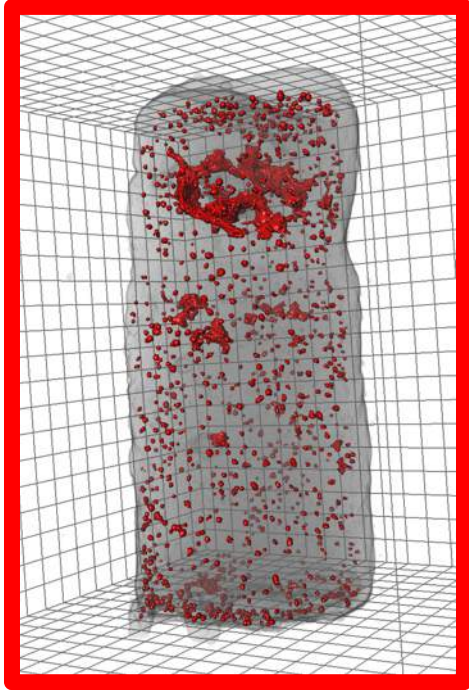
Large pores occur rarely, but these dominate fatigue



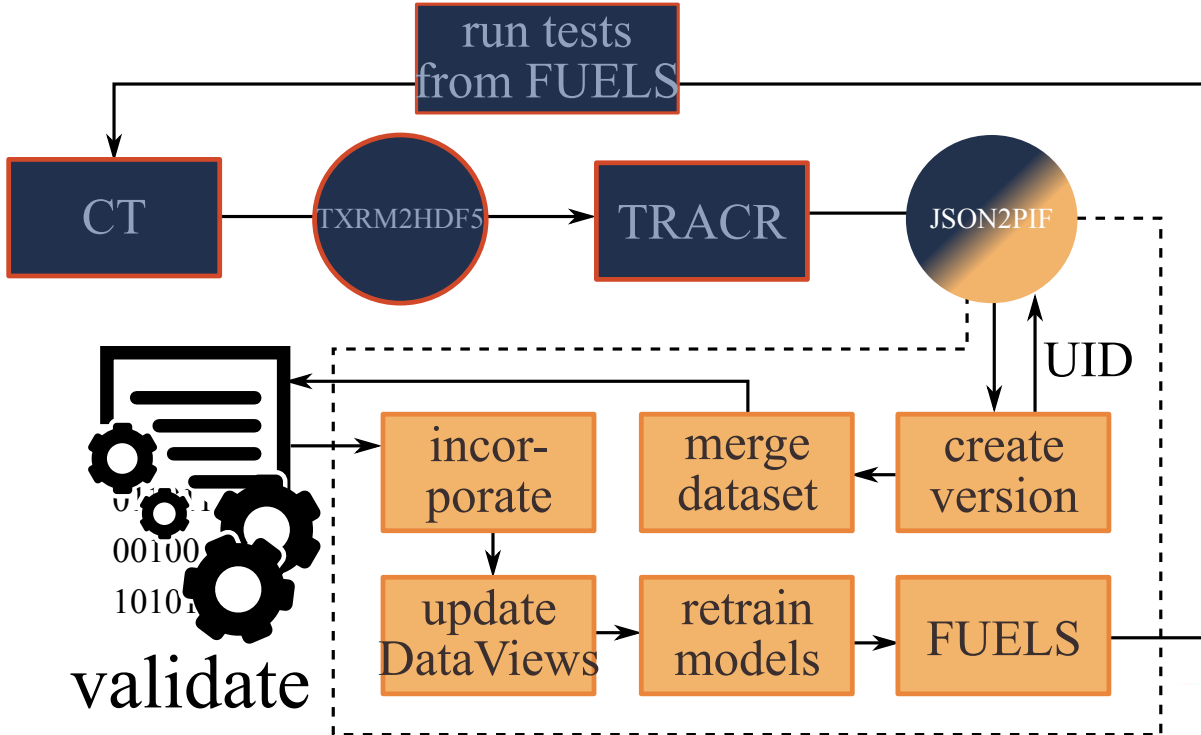
Pore > 200 μm



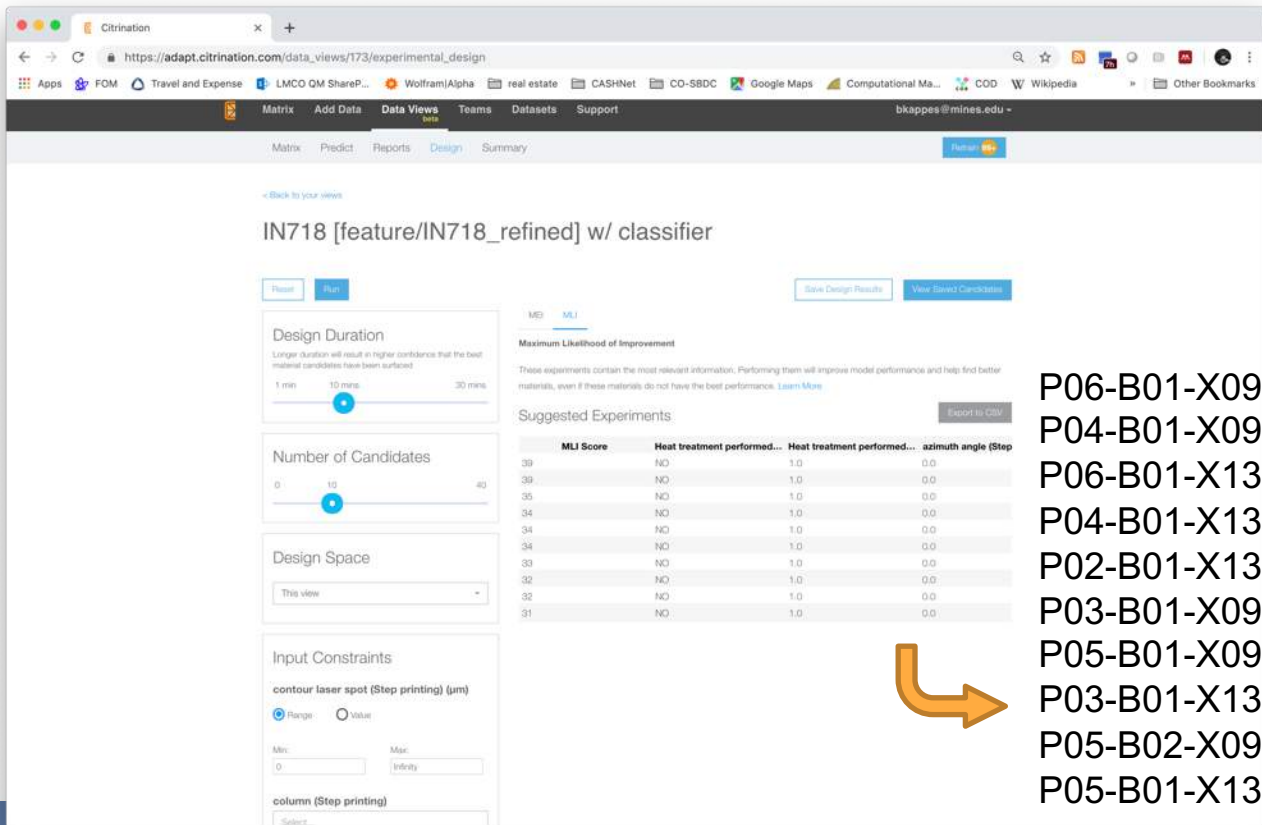
Geometry and build settings affect defect formation



Sequential Learning (SL) to find rare defects



Existing data is used to inform the next test set

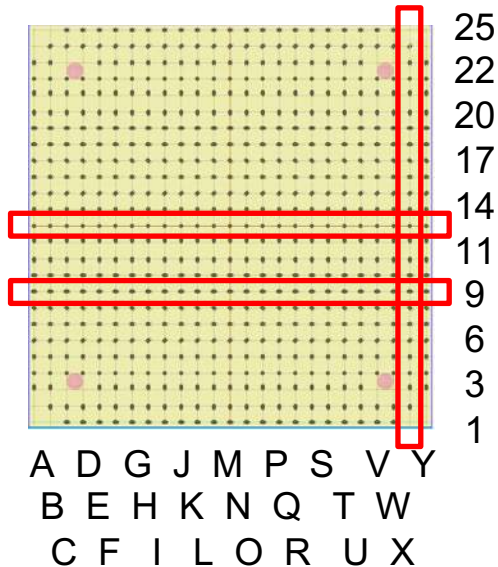


The screenshot shows the Citrination web interface for an experimental design. The main title is "IN718 [feature/IN718_refined] w/ classifier". On the left, there are sliders for "Design Duration" (set to 10 mins) and "Number of Candidates" (set to 10). Below these are sections for "Design Space" and "Input Constraints". On the right, there is a table of "Suggested Experiments" with columns for "MLJ Score", "Heat treatment performed...", and "azimuth angle (Step)".

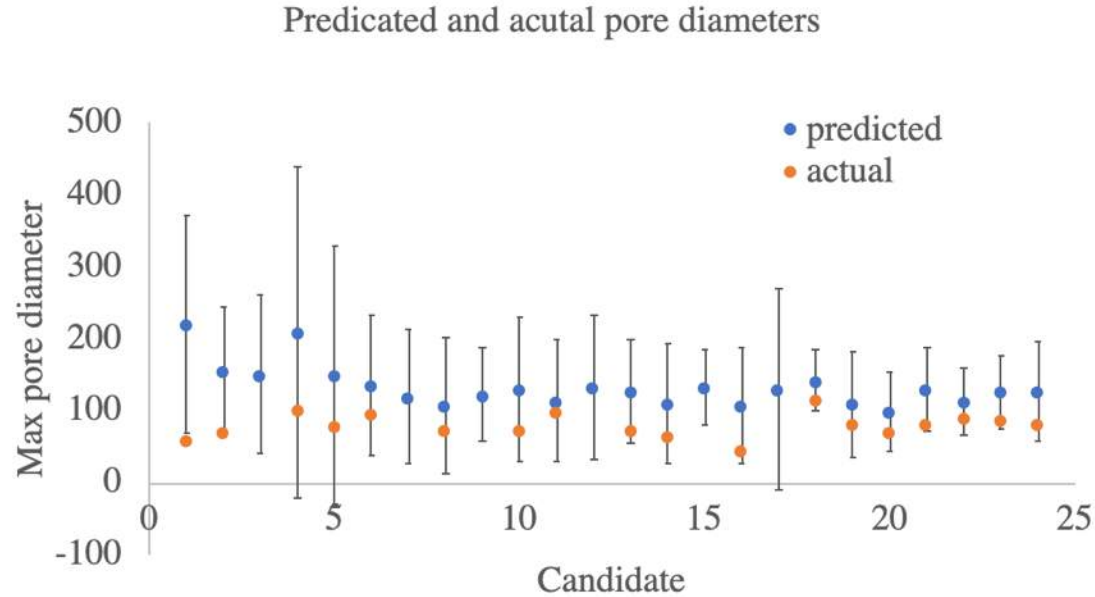
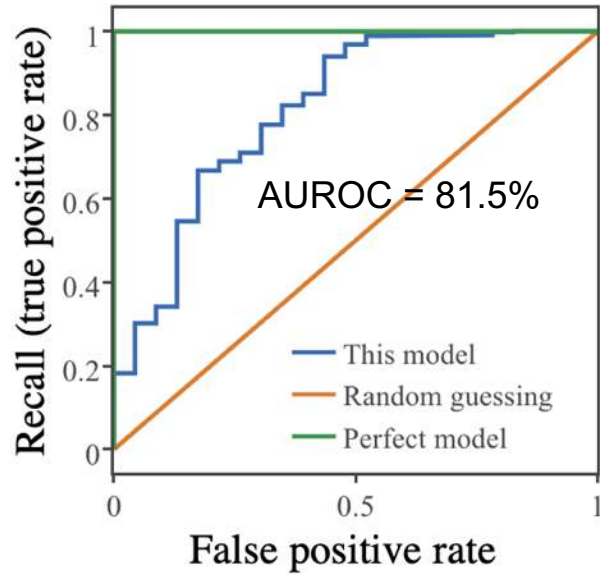
MLJ Score	Heat treatment performed...	Heat treatment performed...	azimuth angle (Step)
39	NO	1.0	0.0
39	NO	1.0	0.0
35	NO	1.0	0.0
34	NO	1.0	0.0
34	NO	1.0	0.0
34	NO	1.0	0.0
33	NO	1.0	0.0
32	NO	1.0	0.0
32	NO	1.0	0.0
31	NO	1.0	0.0



P06-B01-X09
P04-B01-X09
P06-B01-X13
P04-B01-X13
P02-B01-X13
P03-B01-X09
P05-B01-X09
P03-B01-X13
P05-B02-X09
P05-B01-X13



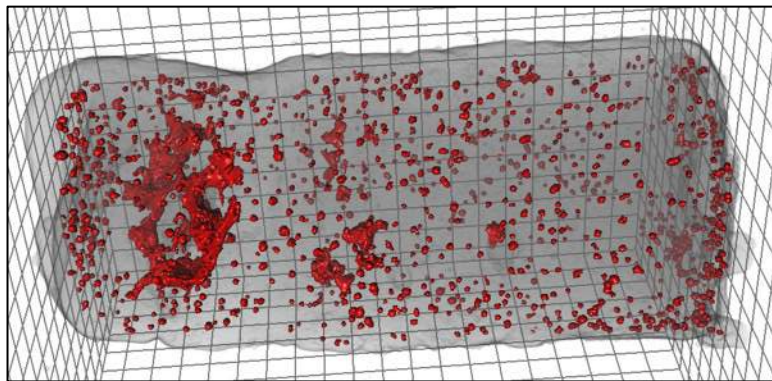
SL improves prediction and exposes variability



Correlating high fidelity to low fidelity measurements

High Fidelity NDE

- X-ray micro-CT

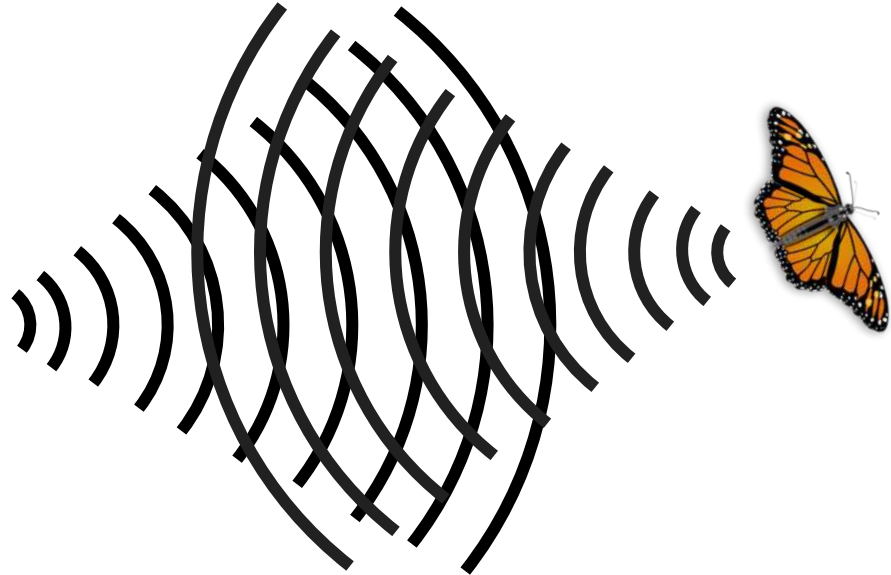


Low Fidelity NDE

- Ultrasonic Testing (UT)
- Radiographic Testing (RT)

Natural application of of ultrasonic: Bats

Sound wave bounces back



•Echolocation

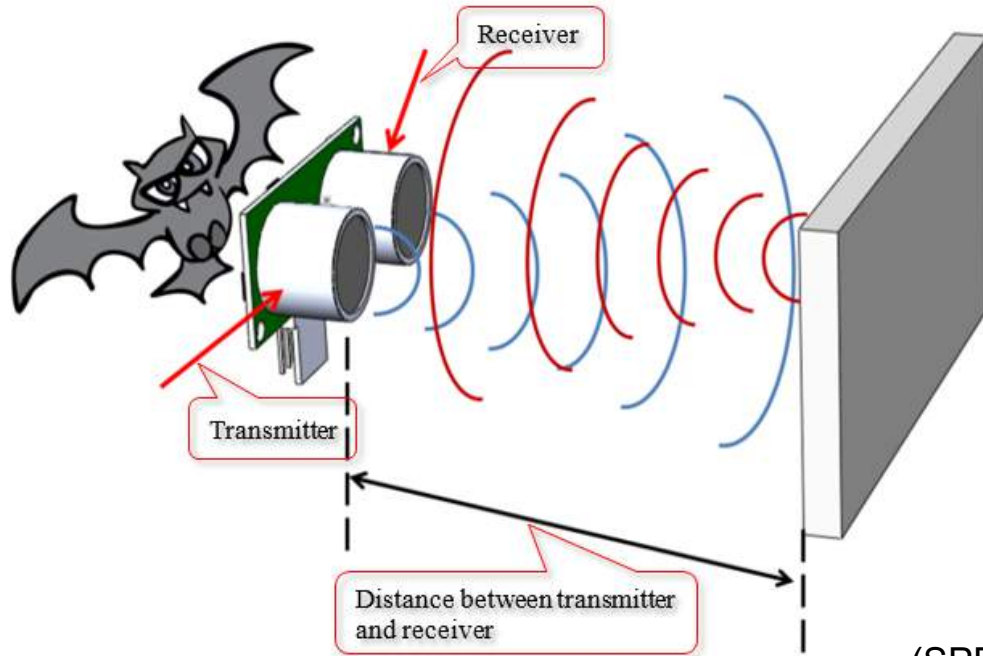


Bat hears reflected sound and knows location

Bat sends sound wave out



Ultrasonic Inspection



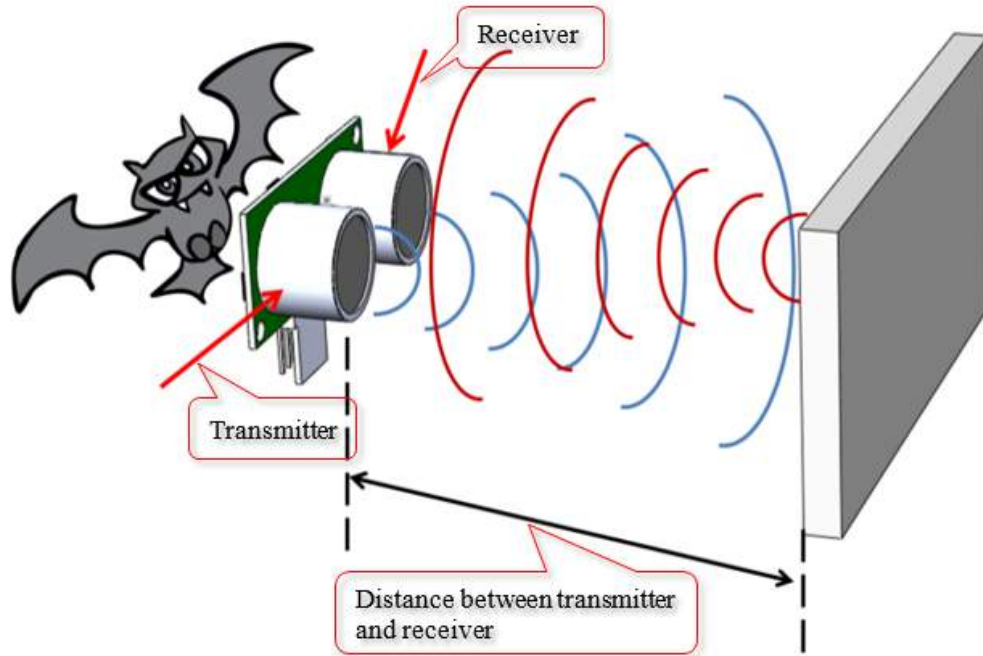
- We know the speed of the waves
- We know the time it took to receive the wave
- We can calculate the distance



$$(\text{SPEED}) \times (\text{TIME}) = \text{DISTANCE}$$



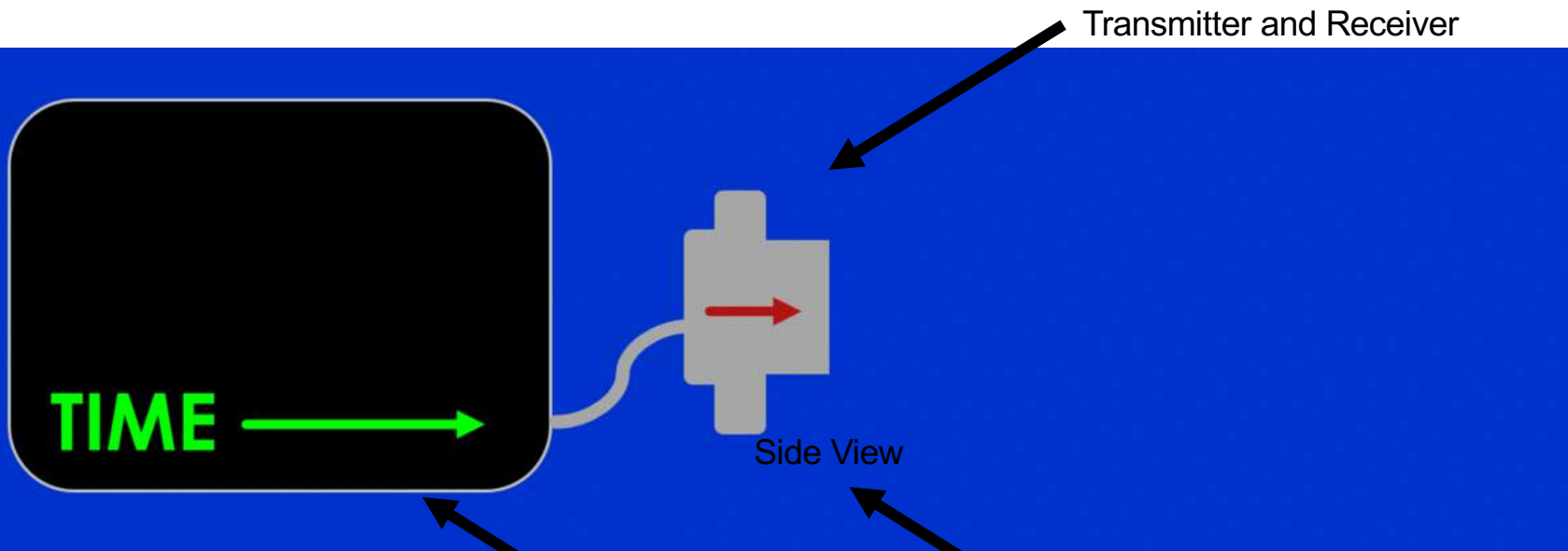
Ultrasonic Inspection



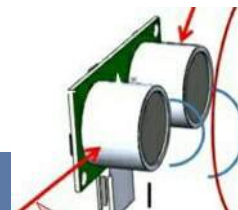
- These waves can move through an object

- We can look into and through the object non-destructively and in-service

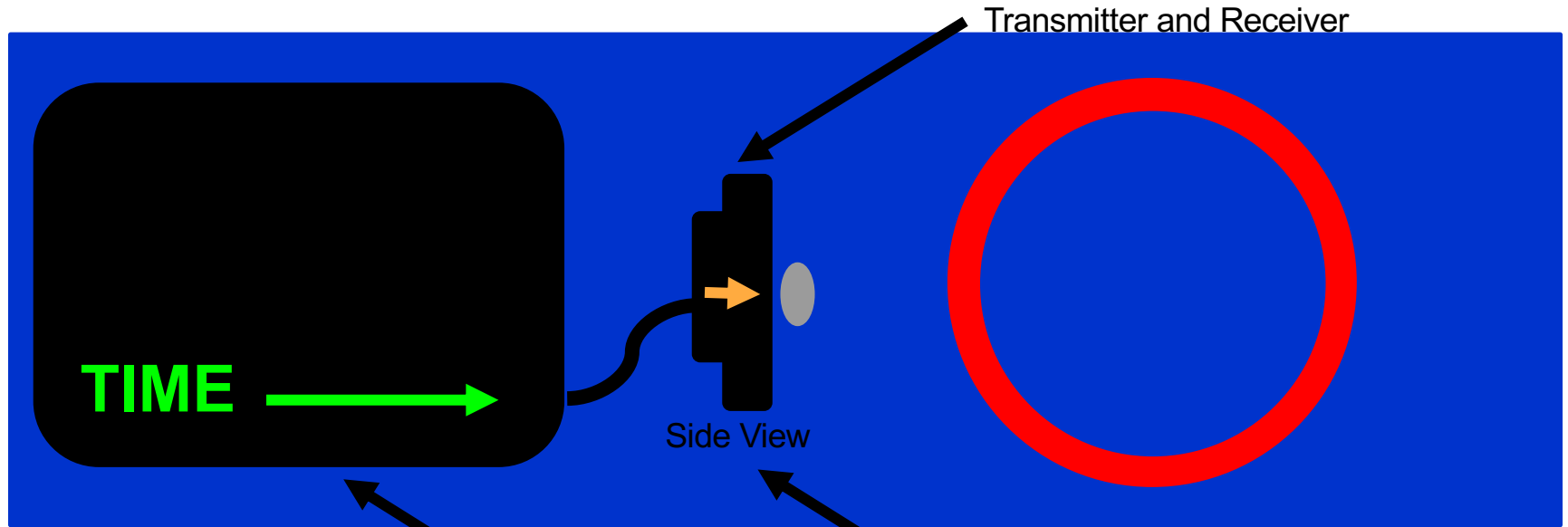
A transducer sends a pulse and measures the echo



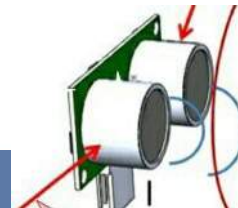
Computer



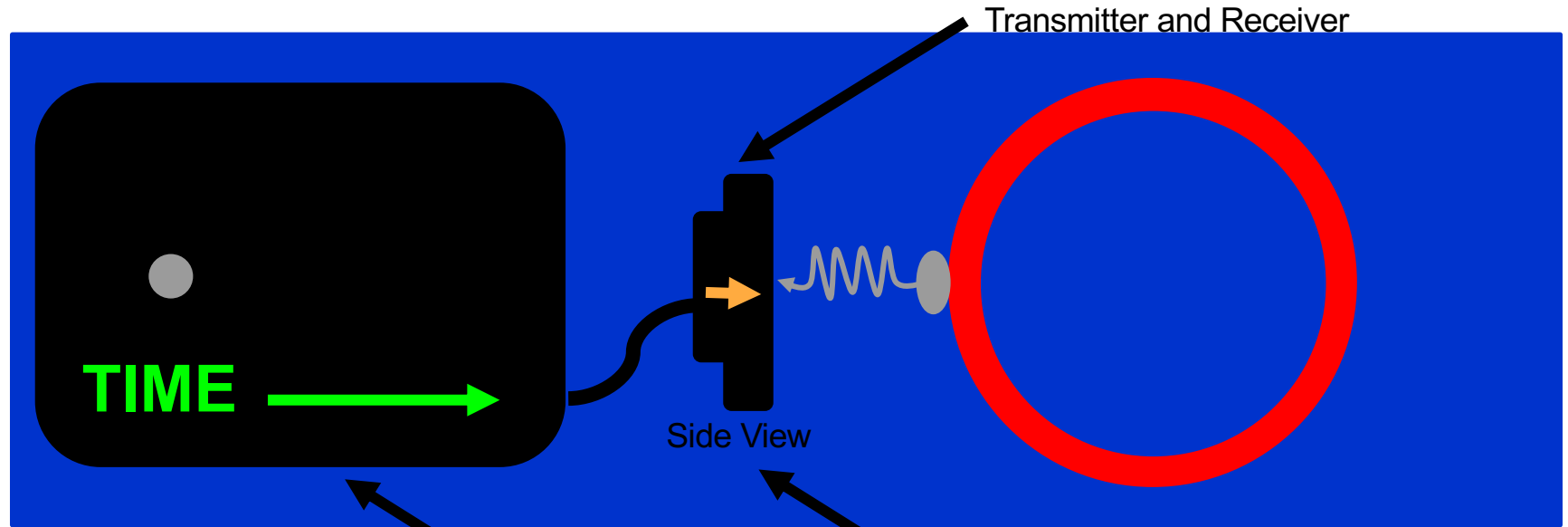
A single transducer gets depth



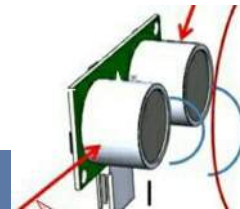
Computer



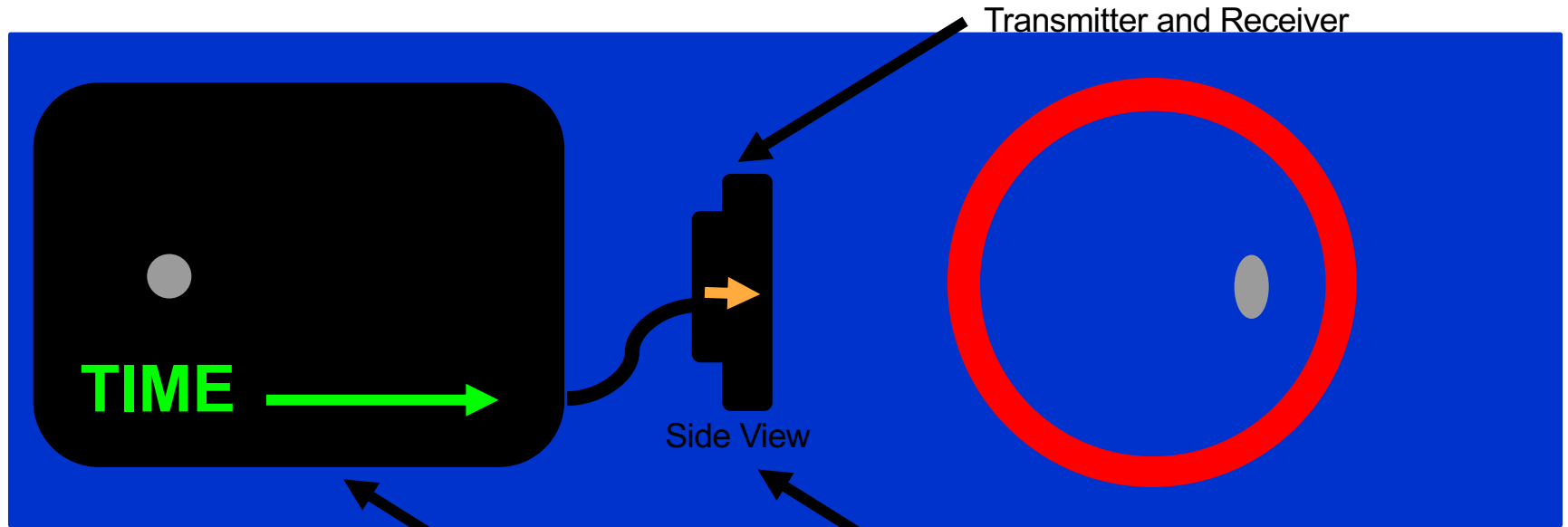
A single transducer gets depth



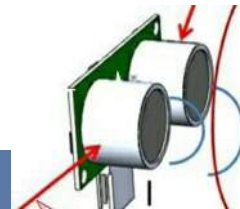
Computer



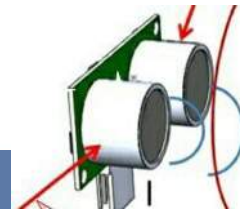
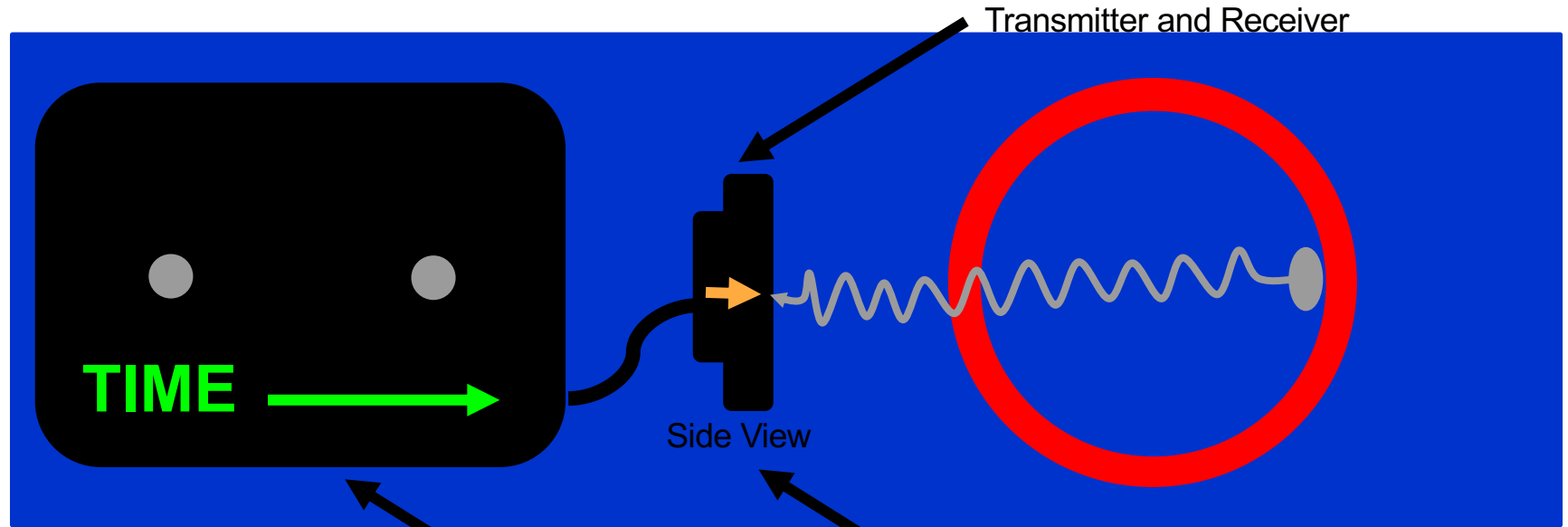
A single transducer gets depth



Computer



A single transducer gets depth

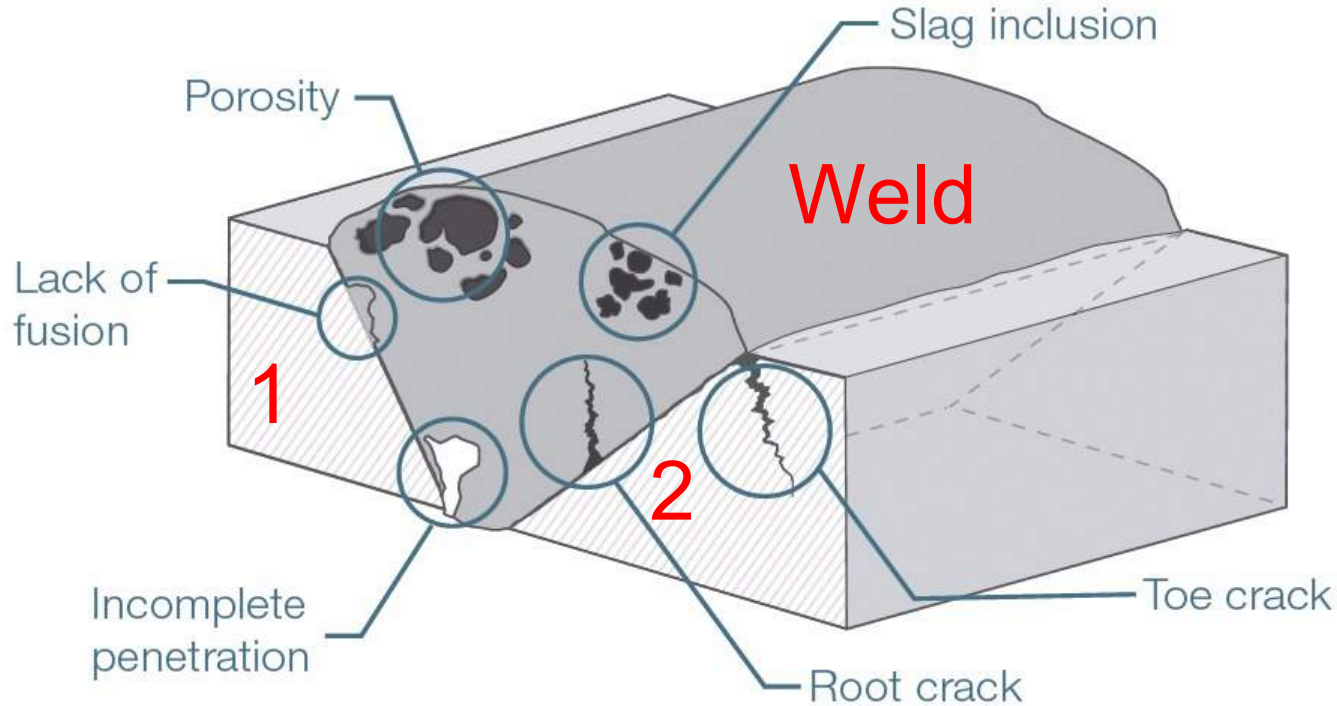


Computer

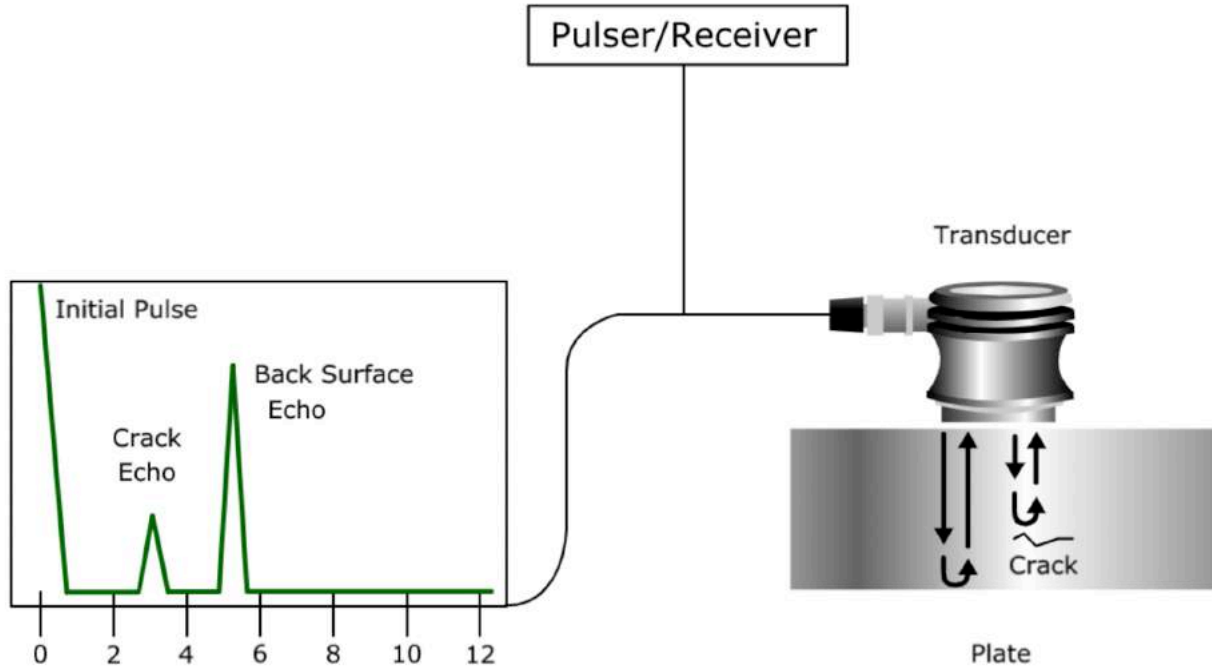
Side View

Transmitter and Receiver

Used for years in welds, UT moves to AM inspection



Feature locations inferred from signal timings

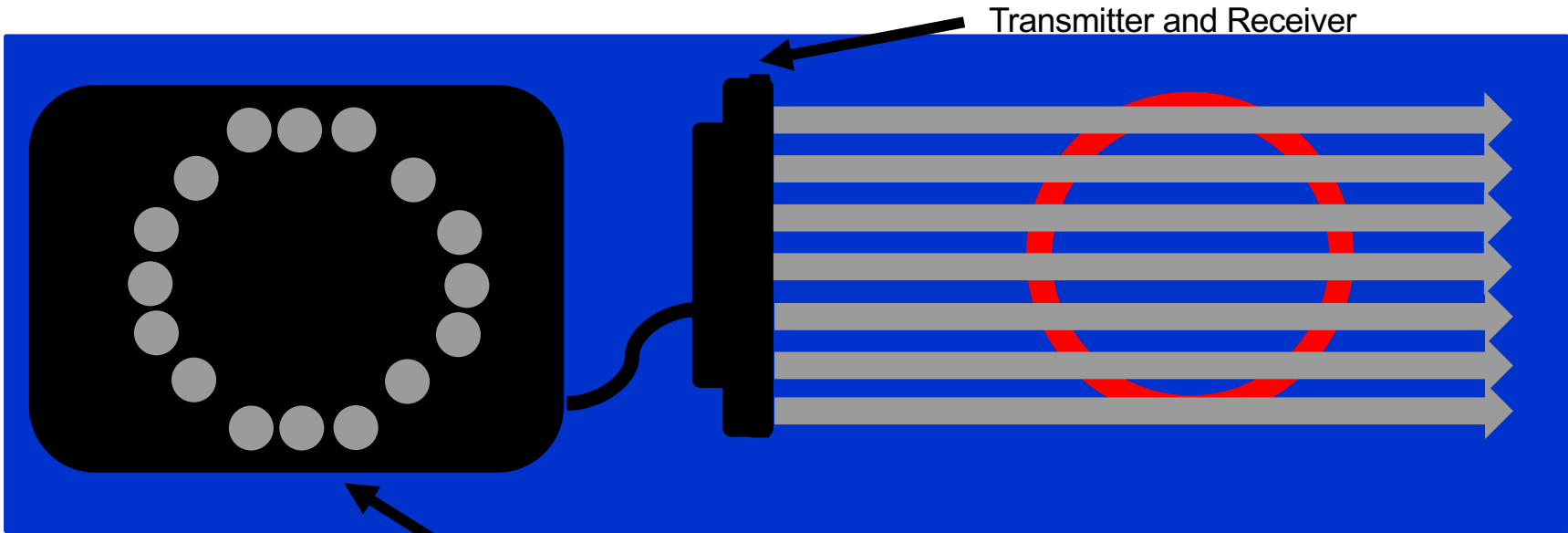


Challenges

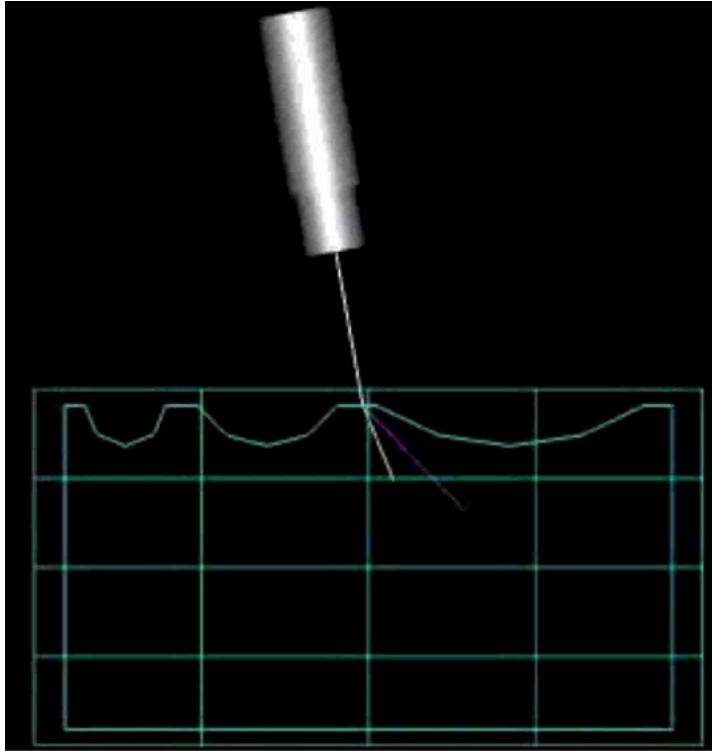
- Changes in the speed of sound.
- Confounding structures: edges, corners, defects.
- Limited spatial resolution.
- Point measurements



Using multiple transducers (phased array) gives shape



Reflections off every surface, crack, pore, and defect



The large number of defects in AM samples makes reconstruction of the UT data challenging.

Correlation of X-ray CT and UT may be an effective way to improve the fidelity of UT for AM.

Conclusions and future work

- Defects have a inordinate effect on dynamic mechanical properties.
- SL directs and improves sampling, reducing the time required to identify and characterize those build conditions that lead to large defects.
- Non-destructive evaluation (NDE), such as UT, are good for in-field examination, but higher fidelity measurements, like X-ray CT, may be used to improve the resolution of UT.

Additional Resources

•Ear:

https://www.google.com/search?q=hearing+ear+cartoon&rlz=1C1GCEFA_enUS831US831&source=lnms&tbm=isch&sa=X&ved=0ahUKEWiXm4uGcvhAhUPR6wKHXYqCv0Q_AUJDqB&biw=1920&bih=969#imgrc=S8GDeq4zssp1QM;

•Bat:

https://www.google.com/search?rlz=1C1GCEFA_enUS831US831&biw=1920&bih=969&tbm=isch&sa=1&ej=ZMGwXM3oBl_2swXFzpaAAw&q=Bat+clipart&og=Bat+clipart&gs_l=img.3..0110.3289.4776.4888...0.0.0.77.454.7.....1....1..gws-wiz-img.....0i67.S-pS83DgRF8#imgrc=lof91wxRqL.DmoM;

•Butterfly:

https://www.google.com/search?rlz=1C1GCEFA_enUS831US831&tbm=isch&q=butterfly+clipart&chips=q:butterfly+clipart_g_1:transparent:oiRSwCaGu44%3D&usq=A14_-kTGQOYSk7hJbUCaAjpS021Injw5bcw&sa=X&ved=0ahUKEWiPvu6kqcvhAhUMKK0KHTJ6BZiQ4YIKigB&biw=1920&bih=969&dpr=1#imgrc=bAhvzlnZcc760M;

•Footsteps:

https://www.google.com/search?rlz=1C1GCEFA_enUS831US831&biw=1920&bih=969&tbm=isch&sa=1&ej=OsGwXMB0D5KltQX996WYBA&q=foot+steps&og=foot+steps&gs_l=img.3..0i2i0i10i2i0i0i10i2i0i0i10i2.19408.21422..21534...2.0..0.80.738.12.....1....1..gws-wiz-img.....35i39i0i67.O-lthsuKDeI#imgrc=OqOZmTw8YQ3_aM;

•Speaking woman:

https://www.google.com/search?rlz=1C1GCEFA_enUS831US831&tbm=isch&q=speaking+clipart&chips=q:speech+clip+art_g_1:transparent:3UkAyRkifAk%3D&usq=A14_-kT_wxmiNge6ugKG2DW83KaNQRW3Rw&sa=X&ved=0ahUKEWif7-an_8rhAhVMFawKHSJMci0Q4YIKigB&biw=1920&bih=969&dpr=1#imgrc=u4S0mNjYCN_eGM;

•Brain:

https://www.google.com/search?rlz=1C1GCEFA_enUS831US831&tbm=isch&q=brain+clipart&chips=q:brain+clipart_g_1:transparent:qLqCEKKzohU%3D&usq=A14_-kSNDGB66hAZqvCbn3VvHnkV9TIMA&sa=X&ved=0ahUKEWiS-rX_8rhAhVHWw0KHXEiAs0Q4YIKigB&biw=1920&bih=969&dpr=1#imgrc=FaKzohACuKqPaM;

•Transducer:

https://www.google.com/search?rlz=1C1GCEFA_enUS831US831&tbm=isch&q=ultrasonic+transducer&chips=q:ultrasonic+transducer_g_1:high+power:-OsKflhidwo%3D&usq=A14_-kTvzRlnXic6oxTXO_s0kR_OTZCJ5w&sa=X&ved=0ahUKEWiO8ZGagMvhAhUSIKwKHRclCeAQ4YILigD&biw=1920&bih=969&dpr=1#imgrc=CndiWH4K6_i93M;

•Receiver:https://www.google.com/search?rlz=1C1GCEFA_enUS831US831&biw=1920&bih=969&tbm=isch&sa=1&ei=ucCwXLqaF4l.6iAXK-ZzABg&q=ultrasonic+sensor&og=ultrasonic+sensor&gs_l=img.3..0i10.2744.3527..3655...0.0.0.76.375.6.....1....1..gws-wiz-img.PQF8crVg_-8#imgrc=bFlq21Ftl.KlwBM;

•Computer:https://www.google.com/search?rlz=1C1GCEFA_enUS831US831&biw=1920&bih=969&tbm=isch&sa=1&ei=BcKwXKuvEcl.SaAw2s4G4Aq&q=computer+stick+figure&og=computer+stick+figure&gs_l=img.3..0i2i0i8i30i8.63079.65845..65958...0.0.0.95.1452.21.....1....1..gws-wiz-img.....35i39i0i67i0i30i0i5i10i30i0i5i30i0i24.d6rl.qfmlPms#imgrc=5xy-QWnc6tCkM;

•3D Print: <https://www.3dprinterreviewsite.com/best-metal-3d-printer/>

•Weld: <http://arcrafpplasma.blogspot.com/2016/11/schematic-representation-of-weld-defects.html>

•Safety: <https://www.pomsassoc.com/safety-management-101-what-every-small-business-needs-to-know/>

•Clock: <https://www.amazon.com/Egert-Clock/dp/B014C3QONC>

•Money: <https://www.kiplinger.com/fronts/channels/money/index.htm>

