MY observations and actions concerning CAI (Composite Affordability Initiative) program

When I transferred from the optics group to be Bob Rapson's assistant, he asked me to "see what you can do to help out the Composite Affordability Initiative (CAI) program. This was a multi-year effort to find ways to make composite materials economically competitive with aluminum for aerospace applications.

At the first CAI meeting that I attended, I met a structural designer from Boeing and asked him how important the cost of the materials used in aero structural designs was. His answer was a shock to me – "I do not care about the cost of the material, I only care about the cost of the structure." "If you can make bonding of composites reliable then a composite structure would be cheaper, and I am all ears."

During the PABST (Primary Adhesively Bonded Structural Technology) program, an effort to adhesively bond the aluminum structure of the C-17, it because apparent that the nature of the surfaces of the adherends is critically important to the strength and durability of bonded joint.

The USAF wanted to avoid using bolts and rivets because of their stress concentrating effects on the initiation and growth of fatigue cracks in highly stressed structures. Adhesive bonding eliminates the stress concentrations associated with penetrating fasteners. Bonding is a better method of joining composites because it spreads the stress transferred between components over a larger area. However, this is true *if and only if* bonding can be made dependable. It is most important that the surface of each component must have a high surface energy and be completely free of pernicious contamination; the worst of which are silicones which are quite common in manufacturing facilities.

Based on my previous work in the PABST program on the importance of surface conditions I approached two professors at University of Cincinnati about measuring the surface energy of composite materials prior to bonding. One professor (Prof. Giles Dillingham) took me up on that suggestion and suggested an simple method of measuring surface energy measurements. BTW, my idea of how to do this was a only for composites and Giles approach was more generic and therefore has a wider applications. A key technical point is that surface energy has two components - a polar component and a dispersive component. This is similar to how one describes the impedance of an electrical circuit with a resistive and a reactive component. To measure the energy of a surface, one needs to measure the

contact angles of different drops of standard solutions on the surface in question. These data are then used to solve the Kaelble equation (Kaelble, D. H., "Dispersion-Polar Surface Tension Properties of Organic Solids", Journal of Adhesion, Vol. 2, No. 2, p. 66-81, 1970). From this data one can then specify the surface energy of a composite and estimate the strength of an adhesive bond (Crane, Robert, Dillingham, Giles and Oakley, Brietta, "Progress in the Reliability of Bonded Composite Structures", Applied Composite Materials, Vol. 23, No. 128, p. 1-13, 2016). Giles company (BTG Technologies) markets a device called the "Surface Analyst™" which automatically measures the surface energy of a material. It has become the standard for adhesive bonding in aircraft, automotive and medical device communities. The company has expanded quite rapidly and has four offices at remote locations to teach users how to use the Surface Analyst for a variety of applications ranging from aerospace bonding to the detection of contaminants on medical implants. Giles has retired and now splits his time between two continents.

At this time, I do not know which USAF programs that the Surface Analyst™ has impacted. I do know that both Boeing and Lockheed have purchased multiple units from and have hired some of the staff from BTG Technologies. While there have been several technical publications that point out the importance of the surface energy to composite bond durability, e.g., Gutierrez-Duran, G. and McDaniel, D., "Effect of Surface Contamination on Composite Bond Integrity and Durability", JAMS 2018 Technical Review, 2016 and & Özer, H., "Structural Adhesive Bonded Joints", Özer, H., editor, *Applied Adhesive Bonding in Science and Technology*, IntechOpen, 2018, doi: 10.5772/intechopen.74229.

The most positive assessment of this technological advancement has been comments by several designers at Ryan Air who say that a bonded composite structure will cost between 60% & 75% of that of similar aluminum one. If it had been available much earlier, it could have significantly helped Lear Fan to win certification of their all-composite business jet.