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World War II Airplane Models Advise Long-Term Behavior of Injection Molded Cellulose Acetate Plastic: Visualizing Stress

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On December 7, 1941 the Imperial Japanese Navy unleashed a surprise aerial attack on the United States Naval Base at Pearl Harbor in Hawaii. The United States Navy immediately launched a program to teach aircraft recognition so that military personnel and civilian spotters could distinguish friend from foe in a split second [1]. Millions of model airplanes representing more than 220 types were produced from injection-molded cellulose acetate plastic coated with matte cellulose nitrate paint between 1942 and 1945 [1]. Seven decades later, many are disintegrating spontaneously and catastrophically. 168 model planes in the collection of the Smithsonian National Air and Space Museum that were exhibited together for 35 years are being investigated visually, chemically, and mechanically to understand the complex mechanisms of their deterioration. Because injection molded cellulose acetate was introduced in the late-1920s and became popular as recently as World War II, the deterioration witnessed today is a new phenomenon and its complexities remain to be explained. For stewards of cultural heritage, slowing deterioration in this category of plastic is an urgent challenge. For understanding material failure, this is an uncommon opportunity to study multiple objects made by the same technology and relate their long-term preservation to composition, manufacture, and exhibition over a 35-year period.

Deterioration of the models appears to result in part from a combination of volatile component loss accompanied by shrinkage, exacerbation of internal stress, and fracture. Evolved gas analysis (EGA) of fragmented plastic and X-ray diffraction (XRD) of corroded metal mount screws indicates that organic acids (primarily acetic), diethyl phthalate, and triphenyl phosphate emanate from the models, which supports the hypothesis that deterioration is driven partly by deacetylation of the polymer and plasticizer loss [2]. A combination of historic photographs that detail the manufacturing process (Fig. 1), photographs of the models today and X-radiographs (Fig. 2) show that component loss, shrinkage, and cracking are related to flow-induced residual stress frozen in during fabrication. These conditions have been exacerbated in some cases by exhibit mounts that restrained the models and inhibited movement. Micron scale changes monitored with scanning electron microscopy and chemical analysis by Raman spectroscopy suggest that recrystallization of triphenyl phosphate contributes to the extreme fracturing observed [3].

The presentation will describe these results and the challenges of imaging low density plastic artifacts with digital X-radiography.

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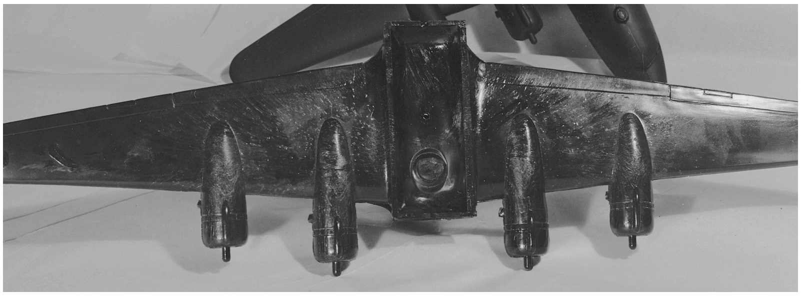

Figure 1. World War II era photograph of a unpainted wing section. Injection point on fuselage and flow lines visible on surface indicate potential stress points and sites of future shrinkage and cracking.

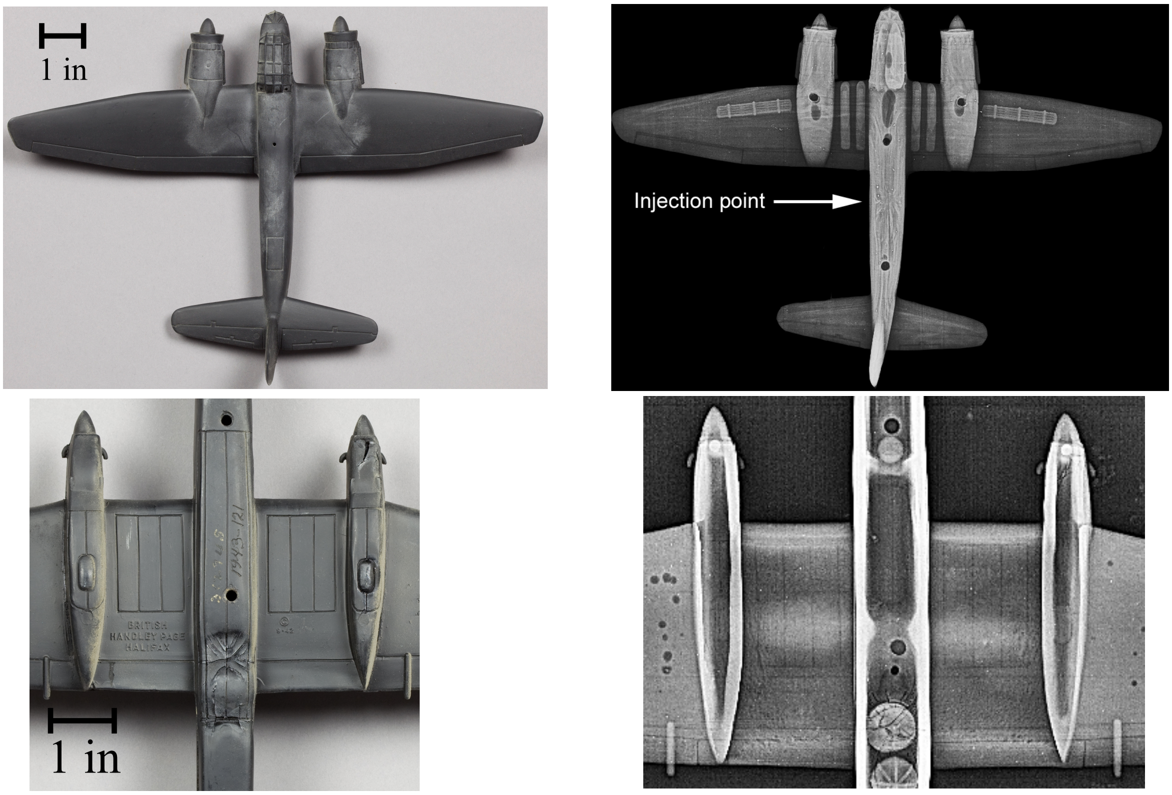

Figure 2. Photograph (top left) and X-radiograph (top right) of a model show correlation between plasticizer bloom on a model's surface and twists in the flow of the plastic melt within, particularly at the injection site, intersection of fuselage with wings, and the engines. Lower images show detail of another model that has sunken and cracked in a similar pattern at the injection point on its fuselage.

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