over the last two years, educator salaries still lag behind private industry pay scales. Other factors such as assignment of research contracts can substantially raise compensation in the academic sector. Overall increases in faculty compensation are associated with appointment to higher rank rather than increased experience within ranks.

Compensation among engineers working at research organizations and those employed as consultants is depicted in Figures 4a and 4b. Finally, the effects of socio-economic changes and shifting industrial emphasis are depicted in Table I, which lists regional variations in median salary.

The complete 1986 EMC study can be obtained by writing to: The American Association of Engineering Societies, Inc., 415 2nd Street, NE, Suite 200, Washington, D.C. 20002.

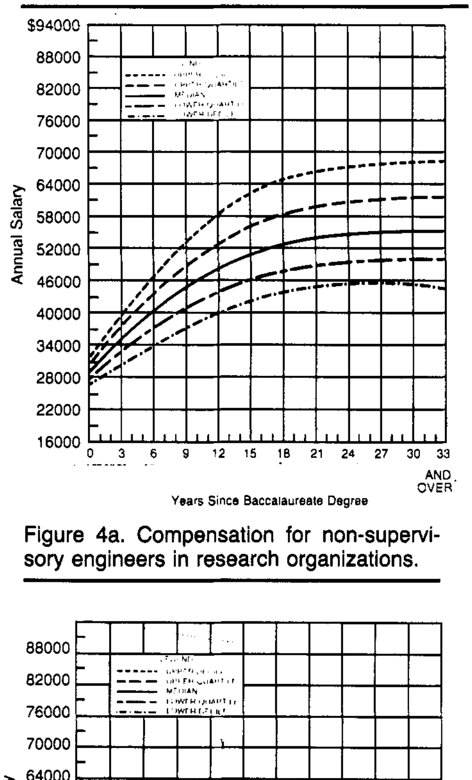

Figure 4a. Compensation for non-supervisory engineers in research organizations.

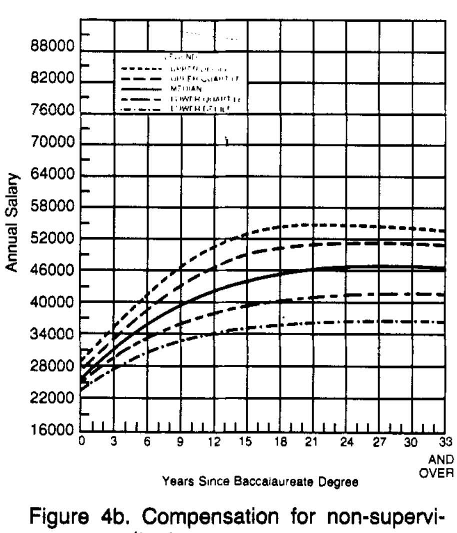

Figure 4b. Compensation for non-supervisory consultants.

MMC Microwave Packaging Components

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Requirements for aircraft and spacecraft microwave devices (e.g., radar and communication systems) under development exceed the capabilities of existing packaging materials. With mechanical and physical properties which can be tailored to the application, metal matrix composites (MMC) give engineers unprecedented opportunities for efficient and reliable packaging designs. The unique properties of metal matrix composites were used to develop new microwave packaging components that, compared to the baseline Kovar, are 65% lighter, have a 600% greater thermal conductivity, and do not distort during or after machining. This obviously represents a major breakthrough in packaging technology.

Microwave circuits use carriers and packages (small boxes) to support ceramic circuit substrates and microwave devices such as field effect transistors. These packages must be machined precisely to avoid misalignment of signal connections with conductors on the substrate, and to prevent bending stresses which can fracture the fragile ceramic substrates and microwave devices mounted on them.

Kovar, a high nickel steel, commonly has been used in this application, primarily because of its low coefficient of thermal expansion (CTE), which is similar to that of alumina ceramic substrates. This CTE match is necessary to avoid both debonding and breakage of the ceramic substrate during the thermal cycling (−65 to 125°C) experienced by military specification electronics. Although the CTE of Kovar is suitable, it has several major deficiencies, including low thermal conductivity, high density, and frequent distortion during and after machining.

The trend to increasing component density means that more heat per unit area must be dissipated. The thermal conductivity of Kovar is only 10 BTU/hr.-ft.-°F, less than 10% of that of pure aluminum. This is a major problem, because the failure rate of microwave devices increases with increasing operating temperature. The density of Kovar is 0.3 lb./in.,^{3} about three times that of aluminum. Kovar packaging components often are a major part of the weight of microwave devices, which is a major design consideration for aircraft and spacecraft systems. Kovar parts typically have high internal stresses which can cause them to distort both during and after machining. The long-term distortion (creep) displayed by Kovar frequently results in parts that exceed tolerances, even though their initial dimensions met specifications.

These deficiencies were remedied by developing microwave packaging components using metal matrix composites. The particular material selected was a 6061 aluminum alloy reinforced with silicon carbide particulates. This material has a low coefficient of thermal expansion, high thermal conductivity, and does not distort during or after machining. The material was purchased from DWA Composite Specialties, Inc.

Alumina ceramic substrates bonded to Kovar and metal matrix composite gold-plated blocks have been thermal cycled without demonstrating bond failure. This success has prompted the development of a variety of microwave packaging components. Identical Kovar and MMC packages were fabricated and tested, and no difference in electrical response was shown.

The demonstrated advantages of the metal matrix composite components represent a major breakthrough in packaging technology. Soldered and welded joint integrity is maintained. Since thermal conductivity is increased 600% over Kovar, the result is cooler, more reliable devices. Packaging weight is reduced by 65%. This weight savings results in further reductions in the weight of supporting structures and fuel. For example, the rule of thumb for fighter aircraft is that each pound of weight saved in avionics decreases takeoff weight by seven pounds. Use of metal matrix composites eliminates the machining and post-machining distortion exhibited by Kovar, reducing scrap rates, rework and schedule problems.

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Correction

In the paper "New Horizons in Electrochemcial Science and Technology" (February 1987 *Journal of Metals,* pages 28-33), Figure 1, which depicts the production of metals and chemicals as well as electroplating, should show a *decrement* for project markets in the period 1990-2000 and not a potential growth.