Awarded Contracts for External Experts to Support the NIST World Trade Center (WTC) Disaster Investigation

Contract No.	Awarded to	Date Awarded
SB1341-03-Z-0022	Applied Research Associates, Inc. (ARA)	9/23/2003

ANALYSIS OF AIRCRAFT IMPACTS INTO THE WORLD TRADE CENTER TOWERS

Under solicitation number SB1341-03-Q-0334, an indefinite deliverable, indefinite quantity (IDIQ) purchase order has been awarded to APPLIED RESEARCH ASSOCIATES, INC. (ARA) of Albuquerque, New Mexico:

ARA is an engineering firm that specializes in the following areas: nonlinear structural dynamics under blast and impact loading, vehicle crashworthiness and impact behavior, aircraft impact analysis, dynamic fracture modeling and failure analysis, impact and penetration mechanics, probabilistic engineering mechanics, and structural engineering. ARA is well qualified to conduct the analysis of the aircraft impact into the WTC towers with active research programs in crash, impact, and blast damage of structures for over 20 years. ARA is selected by the Federal Highway Administration as a Center of Excellence in finite element crash analyses and is designated by Livermore Software Technology Corporation (the developer of the LS-DYNA software package) as a Research Collaborator. Specific examples of the team's past work include:

- Analysis of aircraft impact into nuclear power plant containment structures and storage containers.
- Analysis of a fighter aircraft impact into multiple reinforced concrete barriers.
- Fragmentation of aircraft components due to turbine rotor failure.
- Simulation of railcars in high-speed impacts.
- Studies of the effects of blast on buildings and their progressive collapse.

The specific tasks that ARA will perform include:

1) Provide estimates of the damage to structural systems due to aircraft impact – including exterior walls, floor systems, and interior core columns.
2) Provide estimates of the aircraft fuel dispersal during the impact.
3) Provide estimates and contours of accelerations and deformations as a function of time in each of the two towers due to aircraft impact to be used for estimating damage to fire proofing.
4) Provide a database of the major fragments of the aircraft and destroyed structural components of the towers to be used for estimating damage to the mechanical and architectural systems inside the towers.

The impact analyses will be conducted at various levels including: (1) the component level, (2) the subassembly level, and (3) the global level to estimate the probable damage to the towers due to aircraft impact. The analyses will also include simplified and approximate methods. Analysis of uncertainties using the component, subassembly, global, and simplified analyses will also be conducted to assess the effect of uncertainties associated with various parameters on the damage estimates.

The team from ARA combines engineers from several branches of ARA with diverse background and experience in crashworthiness, dynamic fracture analysis, applied mechanics and nonlinear dynamics, probabilistic mechanics, constitutive modeling, and structural engineering. The team is led by the three engineers with relevant backgrounds and appropriate knowledge in impact and crashworthiness studies. Select experience of these key project personnel is summarized below:

- Dr. Steven W. Kirkpatrick is the program manager for this project. Dr. Kirkpatrick is a senior engineer with 19 years of experience in vehicle crashworthiness, structural dynamics, finite element analysis, impact and penetration mechanics, and failure analysis. He has more than 80 publications in these areas. His research experience includes a wide range of government and commercial projects for rail, highway, civil, military, and aerospace applications. He has been a program leader for many studies requiring close collaboration between experimental and computational efforts with emphasis on model validation. Dr. Kirkpatrick has a doctorate in mechanical engineering from Stanford University.
- Dr. B. Samuel Holmes is the program supervisor for this project. Dr. Holmes is a principal engineer with 40 years of experience in vehicle crashworthiness, structural dynamics, failure analysis, and fluid mechanics. He has served as a program manager and group leader for a variety of projects combining analysis and experiments. He acted as principal investigator for studies of train crashworthiness and the design of a crashworthy locomotive cab, and automobile accidents including compatibility and structural design for high speed impact, train aerodynamics, and impact. His experience also includes studies of weapons and blast effects on large structures. He has more than 40 publications in these areas. Dr. Holmes has a doctorate in applied mechanics from Drexel University.
- Dr. Justin Wu is the technical lead in performing the uncertainty analysis of this project. Dr. Wu is the director of probabilistic engineering at ARA. He is a renowned expert in probabilistic methods with 20 years of experience in the development and application of innovative physics-based probabilistic methods for a wide range of applications including structural reliability analysis and design of space shuttle, aircraft, offshore pipeline, power plant, and automotive; nuclear waste repository risk assessment, and hard target uncertainty analysis. Dr. Wu heads the development of ARA's ProFES (Probabilistic Function Evaluation System) software package, previously supported by the Air Force and NASA. He also leads the development of methodologies and software tools for hard target uncertainty analysis for DTRA, reliability-based multi-disciplinary design for NASA, and rotorcraft probabilistic damage tolerance analysis for FAA. He has more than 100 publications. Dr. Wu has a doctorate in mechanical engineering from University of Arizona.

Other key ARA team members include:

- Dr. Robert Bocchieri, Senior engineer, will provide expertise in constitutive modeling, rate-dependent material behavior, fracture mechanics and failure analysis, finite element analysis, structural dynamics, and crashworthiness. Dr. Bocchieri has a doctorate in aerospace engineering from the University of Texas at Austin.
- Dr. Lawrence A. Twisdale, Principal Engineer/Scientist, will provide expertise in structural engineering and building performance. Dr. Twisdale is a licensed professional engineer and has a doctorate in civil engineering from the University of Illinois.
- Mr. Robert Frank, Principal Engineer/Scientist, will provide expertise in structural mechanics, structural dynamics, finite element analysis, and development and application of simplified response models. Mr. Frank is a licensed professional engineer and has a Master of Science degree in civil engineering from the Massachusetts Institute of Technology.

In addition, the ARA team is augmented by the following experts:

- Dr. P. V. Banavalkar, President of Ingenium Inc., will provide expertise in the analysis and behavior of high-rise steel structures. Dr. Banavalkar has over 40 years of project experience and ten of his building designs are listed in "100 of the World's Tallest Buildings" published in 1998 by the Council of Tall Buildings and Urban Habitat. His experience includes design for all conditions including critical seismic regions, blast-resisting structures and systems for prevention of progressive collapse. His notable projects include Library Tower in Los Angeles, Fountain Place in Dallas, Chase Tower in Houston, and U. S. Bank Place in Minneapolis. As a leading expert in his field, Dr. Banavalkar has authored more than 40 publications and lectured extensively on subjects such as steel structures, seismic stress, and concrete. Dr. Banavalkar is a licensed professional engineer and has a doctorate in civil engineering from Cornell University.
- Dr. Matthew H. Koebbe, independent consultant, will provide expertise in finite element modeling and automatic mesh generation, and nonlinear dynamics. Dr. Koebbe has a doctorate in Mathematics from the University of California, Santa Cruz.