

**N 9 2 - 2 2 7 6 2**

**Composite Overwrapped Nickel-Hydrogen Pressure Vessels**

**John Reagan, NASA Lewis Research Center  
Joe Lewis, TRW**

**PRECEDING PAGE BLANK NOT FILMED**

## COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- THE PURPOSE OF THIS PAPER IS TO STIMULATE INTEREST IN COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS.
  - COMPOSITE OVERWRAPPED PRESSURE VESSELS SHOULD:
    - BE MORE ECONOMICAL TO PRODUCE
    - REQUIRE LESS SCHEDULE TIME TO PRODUCE
    - BE MORE RELIABLE
    - BE INHERENTLY MORE RESISTANT TO FATIGUE DAMAGE
    - POTENTIALLY IMPROVE HEAT TRANSFER CHARACTERISTICS
    - REDUCE MEMBRANE STRESS
    - ALLOW A POTENTIALLY WIDE RANGE OF LINER MATERIALS
- 

**States purpose of paper - stimulate interest in Composite Overwrapped pressure vessel technology as applied to Nickel-Hydrogen Battery pressure vessels. Includes technical and economic forces that could be utilized in such a design.**

## COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- o HISTORY OF NICKEL-HYDROGEN PRESSURE VESSELS
  - o TECHNOLOGY IS FIFTEEN YEARS OLD
  - o EXCEPT FOR THE LAST TWO YEARS ALL KNOWN APPLICATIONS HAVE BEEN IN GEO ORBIT AT 800 PSI
  - o OVER THE LAST THREE YEARS APPLICATIONS HAVE MOVED TO LEO ORBITS WITH PRESSURE INCREASED TO EXCESS OF 1000 PSI
    - o DEPTH OF DISCHARGE HAS ALSO BEEN INCREASED FROM 10% TO PRESENT REQUESTS THAT ARE NOW APPROACHING 40%
    - o WEIGHT HAS BEEN REDUCED AT THE EXPENSE OF PRESSURE VESSEL WALL THICKNESS
  - o BOTH EUROPE AND JAPAN ARE PLANNING NICKEL-HYDROGEN BATTERIES FOR SPACE APPLICATIONS

\*\*\*\*\*

## COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- o HISTORY (cont)
  - o INCONEL 718 HAS BEEN THE MATERIAL OF CHOICE SINCE EARLY DESIGNS
    - o ALL PRESENT DESIGNS KNOWN TO THE AUTHORS PRESENTLY USE OR ANTICIPATE THE USE OF INCONEL 718
    - o INCONEL 718 HAS PROVED TO BE VERY RELIABLE
  - o THE ADVANTAGES OF COMPOSITE OVERWRAPPED MATERIAL HAVE BEEN SUGGESTED SEVERAL TIMES BUT THE TECHNOLOGY HAS ALWAYS BEEN ELIMINATED EARLY ON DUE TO:
    - o FEAR OF ADVERSE THERMAL REACTIONS' EFFECTS
    - o UNKNOWN OF DESIGN
    - o LACK OF COMPOSITE OVERWRAPPED EXPERTS IN THE DESIGN PROCESS
  - o DESIGNERS HAVE ACKNOWLEDGED THE ABILITY OF COMPOSITE OVERWRAPPED TECHNOLOGY TO REDUCE THE OVERALL STRESS IN THE CRITICAL GIRTH WELD(S) AREA

---

**Presents the history of Nickel Hydrogen Pressure Vessels over the last 15 years including materials, operating conditions, and market expansion to internationals.**

**Discusses minor interest in Composite Overwrap technology as applied to Nickel-Hydrogen Batteries to date.**

## COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- o MATERIAL PROPERTIES DESIRED FOR PRESSURE VESSEL
    - o COMPATIBILITY WITH KOH
      - o GENERAL CORROSION
      - o FRACTURE CONTROL
    - o GOOD THERMAL CONDUCTIVITY
    - o HIGH STRENGTH-TO-WEIGHT RATIO
    - o HIGH CYCLE LIFE
      - o APPROXIMATELY 41,000 ACTUAL CYCLES FOR 15 YEAR SERVICE LIFE
        - o 164,000 ANALYTICAL CYCLES
- 

Itemizes basic materials properties: thermal, corrosion, strength.

## COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- o APPROACHES TO ACHIEVING DESIRE PROPERTIES
    - o MONOLITHIC METAL CONSTRUCTION
      - o DIFFICULT TO OPTIMIZE PROPERTIES IN ONE ALLOY
      - o COMPROMISE OF SOME PROPERTY USUALLY REQUIRED
    - o COMPOSITE OVERWRAPPED CONSTRUCTION
      - o EACH DESIRED PROPERTY CAN BE OPTIMIZED IN DIFFERENT COMPONENTS OF COMPOSITE VESSEL
        - o COMPATIBILITY IN INNER LINER
        - o THERMAL CONDUCTIVITY IN OUTER LINER
        - o STRENGTH-TO-WEIGHT RATIO IN COMPOSITE OVERWRAP
        - o CYCLE LIFE IN INNER LINER
- 

**Monolithic and Composite Overwrapped construction approach compared.**

## **COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS**

- **POTENTIAL ADVANTAGES OF COMPOSITE PRESSURE VESSEL**
    - **OPTIMIZED PROPERTIES**
    - **POTENTIALLY LOWER COST**
      - **COMPOSITE HIGH-PRESSURE GAS STORAGE VESSELS COST APPROXIMATELY 20% OF EQUIVALENT TITANIUM VESSEL**
      - **POTENTIAL FOR ELIMINATION OF WELDS**
    - **POTENTIALLY SHORTER MANUFACTURING SCHEDULE**
      - **COMPOSITE VESSELS ARE BEING PRODUCED IN APPROXIMATELY ONE-THIRD TIME FOR EQUIVALENT TITANIUM VESSELS**
    - **IMPROVED FRACTURE CONTROL CAPABILITY**
      - **COMPOSITE VESSELS SHOW POTENTIAL FOR MILLIONS OF CYCLES BEFORE LEAKAGE**
    - **POTENTIALLY LOWER WEIGHT**
      - **COMPOSITE HIGH-PRESSURE GAS STORAGE VESSELS WEIGH APPROXIMATELY 20% OF WEIGHT OF EQUIVALENT TITANIUM VESSEL**
    - **PRECISE CONTROL OF VESSEL WALL GROWTH DUE TO PRESSURE WITH MINIMAL EFFECT ON WEIGHT**
- 

**Detailed description of the advantages of Composite Overwrapped Pressure vessels showing weight savings, manufacturing schedule reductions, and improved fatigue life.**

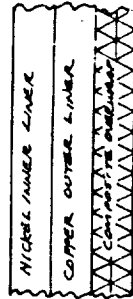
### COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- o GRAPHITE/EPOXY OVERWRAPPED PRESSURE VESSEL WITH INCONEL X-750 LINER IS CURRENTLY FLYING ON B-1 BOMBER
- o NO KNOWN REASON WHY INCONEL 718 LINERS OR LINERS OF ANY DUCTILE NICKEL ALLOY COULD NOT BE OVERWRAPPED WITH GRAPHITE/EPOXY

\*\*\*\*\*

### COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

#### OPTIMIZED PROPERTIES



SCHEMATIC SECTION  
OF VESSEL WALL

---

**Discussion of B-1 application, wide range of usable materials, and a sketch of a possible optimized design.**

## COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- o THERMAL CONDUCTIVITY OF SOME CANDIDATE MATERIALS
  - o COPPER: 226 BTU FT/HR FT<sup>2</sup>
  - o NICKEL: 50 BTU FT/HR FT<sup>2</sup>
  - o GRAPHITE: 48 BTU FT/HR FT<sup>2</sup>  
(PARALLEL TO FIBER)
  - o INCONEL 718: 6.5 BTU FT/HR FT<sup>2</sup>
  - o GRAPHITE/EPOXY: 0.1 BTU FT/HR FT<sup>2</sup>  
(TRANSVERSE TO FIBER)

---

**Table showing recent successes using Graphite/Epoxy Composite Overwrapped technology in actual flight systems.**



## COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- o POTENTIAL LINER FABRICATION METHODS
  - o SPIN FORM AND CHEM-MILL
  - o ELECTROFORM AND CHEM-MILL
  - o FORGE AND CHEM-MILL

\*\*\*\*\*

## COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- o POTENTIAL ELIMINATION OF WELDS
  - o JOIN VESSEL COMPONENTS WITH ADHESIVES
  - o USE MECHANICAL CLOSURES WITH NON-STRUCTURAL SEALING WELDS

---

**Discussion of joining technology and the opportunity to: reduce risk in manufacturing, increase production, and improve reliability by adopting Composite Overwrapped technology.**

## COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- o FRACTURE CONTROL ISSUE FOR NICKEL-HYDROGEN PRESSURE VESSELS
  - o NDI METHODS FOR CRACKS ARE NOT SENSITIVE ENOUGH FOR 164,000 ANALYTICAL CYCLES
  - o ENVIRONMENTALLY AFFECTED SUSTAINED LOAD CRACK GROWTH DUE TO EFFECT OF KOH REDUCES CYCLE LIFE

\*\*\*\*\*

## COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- o POTENTIAL FRACTURE CONTROL METHODOLOGY
  - o ELIMINATE STRUCTURAL WELDS
  - o ELIMINATE ALL CRACKS BY CHEM-MILLING INSIDE AND OUTSIDE SURFACES OF LINER

---

**Fracture Control problems in present designs are addressed and possible solutions proposed. Emphasis is on the improvement possibilities with Composite Overwrapped technology in the area of a large analytical increase in total pressure vessel life.**

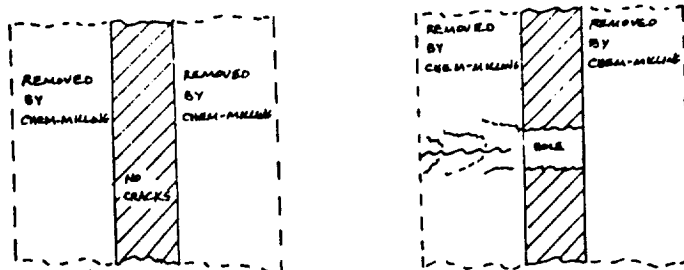
## COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- o NDI METHODOLOGY FOR WROUGHT METAL LINER
  - o WROUGHT METAL IS CONVENTIONALLY MACHINED TO A THICKNESS OF 0.030-0.040 INCH PER SURFACE GREATER THAN FINAL DESIRED THICKNESS
  - o BOTH SURFACES OF WROUGHT METAL ARE INSPECTED USING NISTS "SPECIAL" PENETRANT INSPECTION
  - o EXTRA 0.030-0.040 INCH THICKNESS IS CHEMICALLY MILLED FROM EACH SURFACE
  - o REMAINING MATERIAL IS "CRACK-FREE"
    - o CHEM-MILLING SOLUTIONS DO NOT GENERATE CRACKS
      - o NASA AND DoD SPECIFICATIONS REQUIRE "ETCHING" BEFORE PENETRANT INSPECTION
    - o ANY SURFACE CRACK IN ORIGINAL 0.030-0.040 INCH THICKNESS RESULT IN HOLES THROUGH FINAL THICKNESS

\*\*\*\*\*

## COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- o NDI METHODOLOGY



RESULT IF NO CRACK EXISTS

RESULT IF CRACK EXISTS

Non-destructive testing is described for monolithic designs and for the proposed Composite Overwrapped technology. The elimination of virtually any flaw by using Chem-milling to reduce the overall membrane thickness is detailed. Adopting this technology proves the extended analytical life predicted above.

**COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS**

**FLIGHT HISTORY OF GRAPHITE-OVERWRAPPED PRESSURE VESSELS  
WITH THIN METALLIC LINERS**

| PROGRAM           | TYPE OF TANK | DATE FLOWN | FLUID                | FIBER   | OPERATING PRESSURE (PSIA) | BURST PRESSURE (PSIA) |
|-------------------|--------------|------------|----------------------|---------|---------------------------|-----------------------|
| MEDI              | PRESSURANT   | JAN. 1990  | GN <sub>2</sub>      | T-40    | 7,000                     | 14,000                |
| PEGASUS           | PRESSURANT   | APR. 1990  | GN <sub>2</sub>      | NT 46-9 | 2,500                     | 5,000                 |
| ERIS              | PRESSURANT   | JAN. 1991  | GHe                  | T-1000  | 9,400                     | 24,000                |
| ERIS              | PROPELLANT   | JAN. 1991  | HTO/H <sub>2</sub> O | NT 46-9 | 2,550                     | 6,500                 |
| BRILLIANT PEBBLES | PRESSURANT   | MAR. 1991  | GHe                  | T-1000  | 9,000                     | 23,000                |
| PEGASUS MAPS      | PROPELLANT   | JULY 1991  | HYDRAZINE            | T-1000  | 464                       | 696                   |
|                   | PRESSURANT   | JULY 1991  | GHe                  | T-1000  | 6,000                     | 10,200                |
| MICROSAT          | PRESSURANT   | JULY 1991  | GN <sub>2</sub>      | T-1000  | 5,800                     | 8,700                 |
|                   | PRESSURANT   | JULY 1991  | GN <sub>2</sub>      | T-1000  | 6,000                     | 12,000                |

---

**Pictorial of how NDI combined with chem-milling assure total freedom from flaws.**

## COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS

- o NOW IS THE RIGHT TIME TO STUDY THIS ALTERNATIVE
    - o THE COMPOSITE OVERWRAP TECHNOLOGY HAS TOTALLY SUPPLANTED CONVENTIONAL MONOLITHIC METAL TECHNOLOGY IN MANY SPACE FLIGHT APPLICATIONS IN THE LAST FIVE YEARS
      - o IT IS INHERENTLY SAFER
      - o USED EXTENSIVELY WITH MONOPROPELLANT SYSTEMS AS WELL AS OTHER HIGH PRESSURE APPLICATIONS
      - o LOW-PRESSURE BI-PROPELLANT VESSELS CURRENTLY BEING DEVELOPED
    - o THE USA SHOULD STRIVE TO MAINTAIN ITS TECHNOLOGICAL SUPERIORITY IN THIS TECHNOLOGY BY EXPLORING ALL FACETS AND APPLICATIONS (BOTH NICKEL-HYDROGEN AND COMPOSITE OVERWRAPPED TECHNOLOGIES)
- 

**Suggests that now is the correct time for the USA to thoroughly investigate composite overwrapped technology. This activity will protect our market share while promoting greater knowledge of Nickel-Hydrogen Batteries.**

### **COMPOSITE OVERWRAPPED NICKEL-HYDROGEN PRESSURE VESSELS**

- **A PRELIMINARY INVESTMENT OF 300k\$ WOULD BE ADEQUATE TO DEVELOP THE BASIC FEASIBILITY OF PRODUCING SUCH A DESIGN.**
    - **THIS INVESTMENT WOULD PRODUCE A PROTOTYPE PRESSURE VESSEL ALONG WITH ALL PRELIMINARY DATA REGARDING THERMAL PROPERTIES, MANUFACTURING METHODS AND FRACTURE CONTROL**
    - **A MANUFACTURING PLAN WOULD ALSO BE ESTABLISHED WITH COST PER UNIT ESTIMATED FOR PRODUCTION**
  - **WORK COULD BEGIN IN 3 - 6 MONTHS**
  - **COMPLETION WOULD BE EXPECTED IN 18 - 20 MONTHS**
- 

**Presents cost and schedule information.**