Approaches to CMC Component to Metal Component Attachment

HT-CMC 11
11th International Conference on High Temperature Ceramic Matrix Composites
August 27-31, 2023 | Jeju, Korea

presented in ***Joining and Integration for CMCs II*** (paper: 11-0242)

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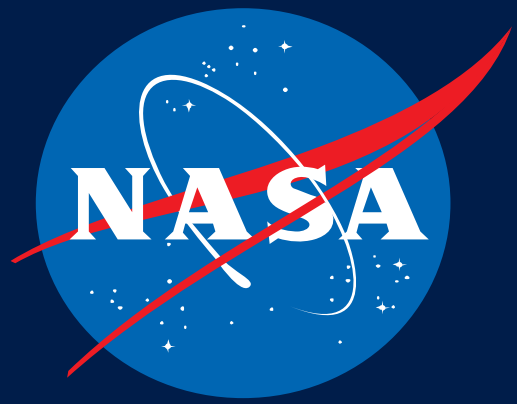


Distribution A

Outline

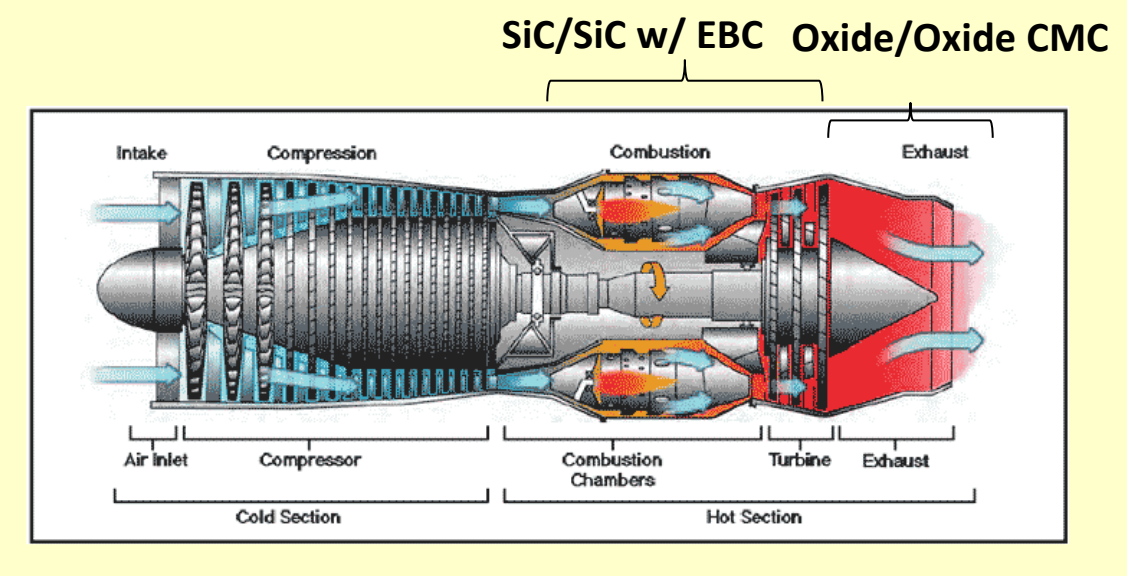
- Current Hot Section SiC/SiC CMC Component Applications in Gas Turbine Engines
- Objective
- CMH-17 Vol 5 (CMC Handbook)
- Approach (Focus on Mechanical Attachments)
- CMC to Metallic Component Attachment Literature (Hot Section SiC/SiC CMC Components Focus)
- Attachment Requirements, Issues, and Challenges
- Discussion of Selected U.S. Patents for Attaching CMC Components to Metallic Components
- Future Work: Summarizing Results from Assessing U.S. Patents and Attachment Articles/Reports and Getting Further Input From Others
- Acknowledgements

Design of Attachment Features is Critical

- **CMC components need to be attached to a metallic component or fitting in gas turbine engines.**
- **The design and functioning of attachment features is critical to the successful incorporation of CMC components into advanced engines.**

CMC to Metallic Component Attachments: Commercial Aircraft Engines

- **In general, attachment schemes have been developed for two different CMC (ceramic matrix composite) systems that are flying in commercial aircraft turbine engines:**
  - **SiC/SiC engine hot section components**
  - **Ox/Ox exhaust components**



- **SiC/SiC hot section components currently have a melt infiltrated (MI) SiC matrix w/ "hot" surface covered by an EBC (environmental barrier coating). These operate at maximum temperatures of 2000 - 2400°F (1093 - 1315°C).**
- **Ox/Ox exhaust nozzles and center bodies are currently used on engines for business jets and Ox/Ox CMCs may replace other PMC (polymer matrix composites) and metallic engine/exhaust system components in the future. Maximum operating temperatures of 1200 - 1600°F (649 - 871°C).**

Status in 2023: SiC/SiC CMC Components Are Now Flying in Commercial Aircraft Turbine Engines

- **In 2016, General Electric Aviation (GEA) certified CFM International's LEAP engine which incorporates 18 stationary CMC 1st stage high pressure turbine (HPT) shrouds that can withstand temperatures of 2400ºF (1316ºC)*.**

*** temperature at CMC/EBC interface**

high-bypass turbofan engine

courtesy of GE Aerospace

HPT CMC shrouds

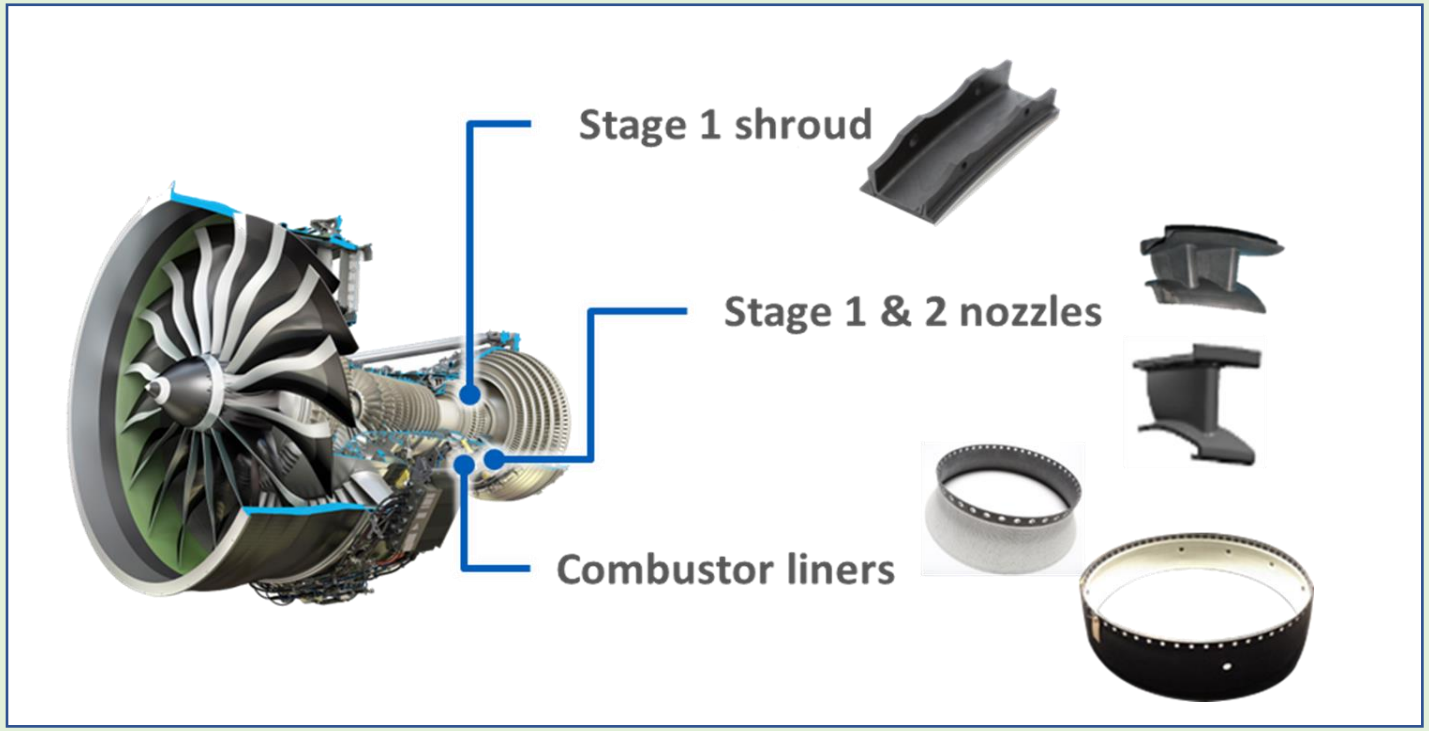
courtesy of GE Aerospace

Refr. 1 - 7

Additional SiC/SiC CMC Components Will Soon be Flying

- **The GE9X engine, which will power the new Boeing 777X, is the largest commercial jet engine in the world.**
- **It will have 42 nozzles and combustor liners and turbine shrouds manufactured from the Prepreg MI SiC/SiC (a total of 107 CMC parts!).**
- **Certified in 2021, it will enter into service in 2025.**

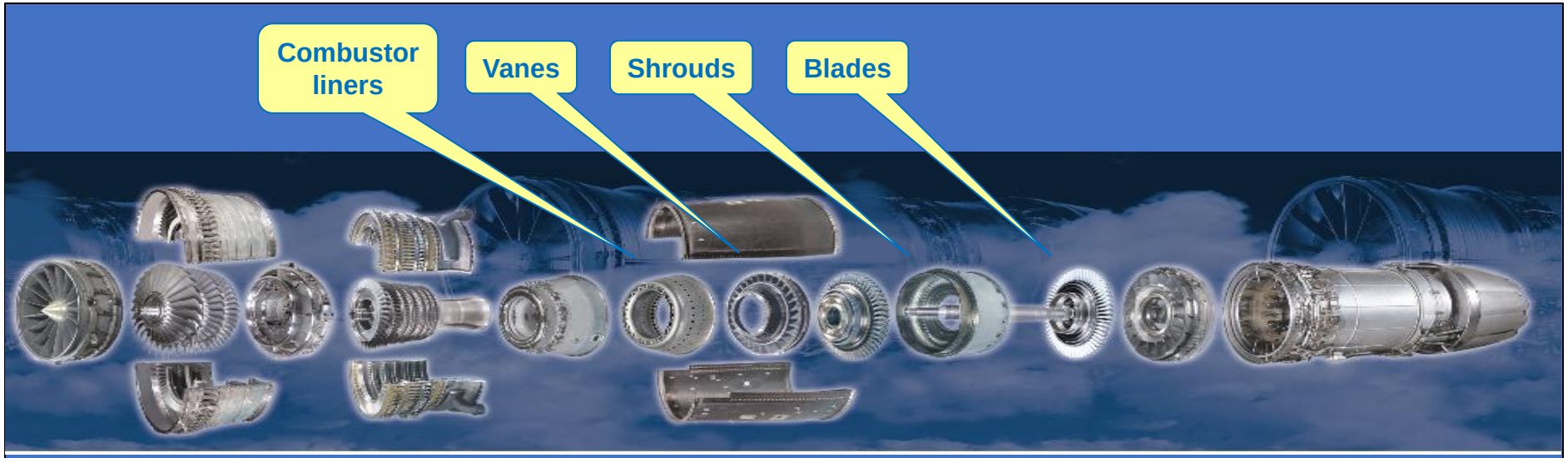
courtesy of GE Aerospace



MI SiC/SiC CMC components for an advanced jet aircraft engine

Refr. 2, 3, 8 - 10

SiC/SiC CMC Turbine Engine Hot Section Components



2400°F (1316°C)* Today 2700°F (1482°C) Future

The GE Prepreg MI SiC/SiC CMC offers 300-400°F higher operating temperature capability than SOA nickel superalloys

Development of a 2700°F Capable* SiC/SiC CMC offers the potential for additional significant fuel burn reduction

* temperature at CMC/EBC interface

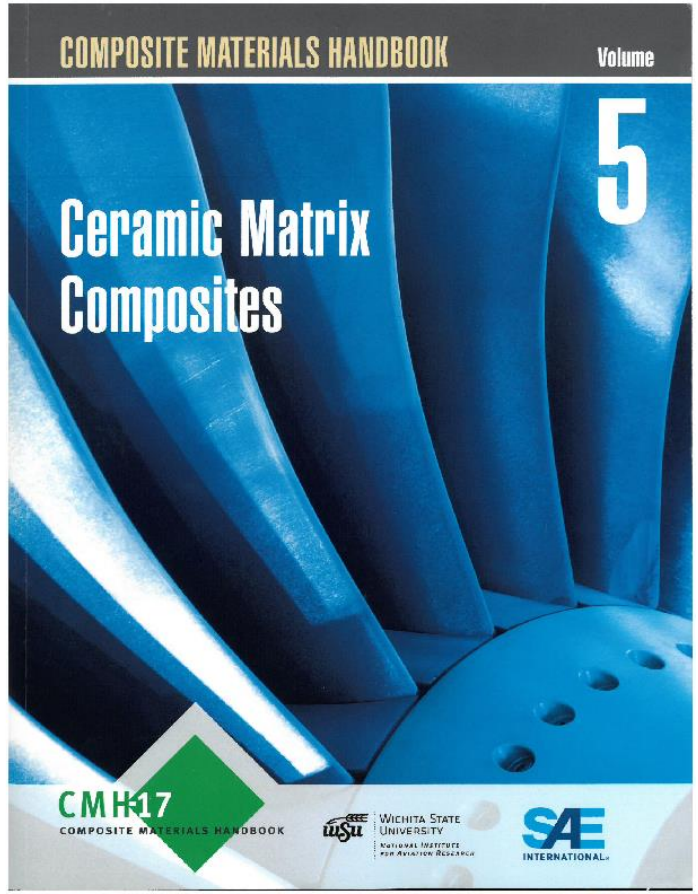
Refr. 2, 3, 11, 12

Objective

- **The Objective of this effort is to document relevant “Attachment” information and prepare a section on “Approaches to CMC Component to Metal Component Attachment” for CMH-17 Vol 5.**
- **This information will also be useful to NASA engineers who support NASA HyTEC (Hybrid Thermally Efficient Core Project).**

Composite Materials Handbook-17, Volume 5

- The Composite Materials Handbook-17, Volume 5 on ceramic matrix composites is available* as a useful guide for CMCs:
  - CMC Materials / Processing
  - Design / Analysis Guidelines
  - Testing Procedures
  - Data Analysis and Acceptance
- It continues to be developed w/support from volunteer technical experts from U.S. Industry, Government, and Academia
- Release of Volume 5B in 2024



Courtesy of SAE International

Refr. 1

Want to add information on **Attachment of CMC Components to Metallic Components**

* **Publication – through SAE International**

Approach

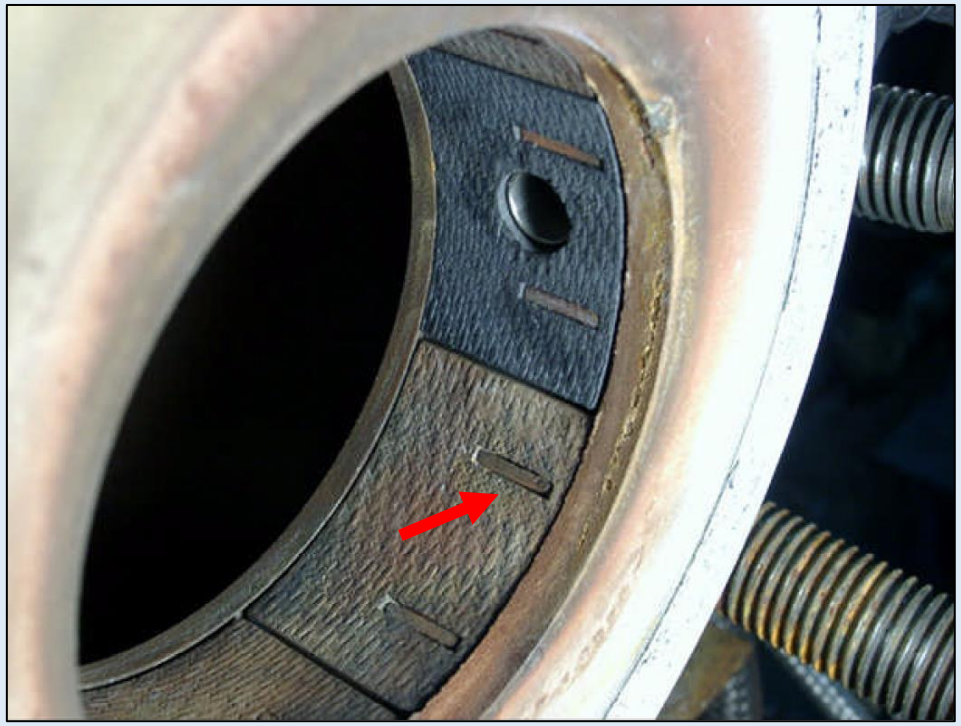
1) **Use open literature and U.S. Patents to obtain and summarize information with a focus on mechanical attachment technology, *and***

2) **Request additional input from OEM (Original Equipment Manufacturer) engineers.**

CMC to Metallic Component Attachment Literature

- Literature searches performed on CMC to metal component attachment.
- Articles were found, with some related to TPS (thermal protection system) / hot structures attachment (Refr. 13).
- Have various articles in-hand that show how CMC subelements and test articles were mounted in testing rigs (Refr. 14, 15, 16).
- Overall, there does not seem to be much open literature that describes attachment designs. This is due to the proprietary nature of this technology.

Refr. 14



Refr. 15

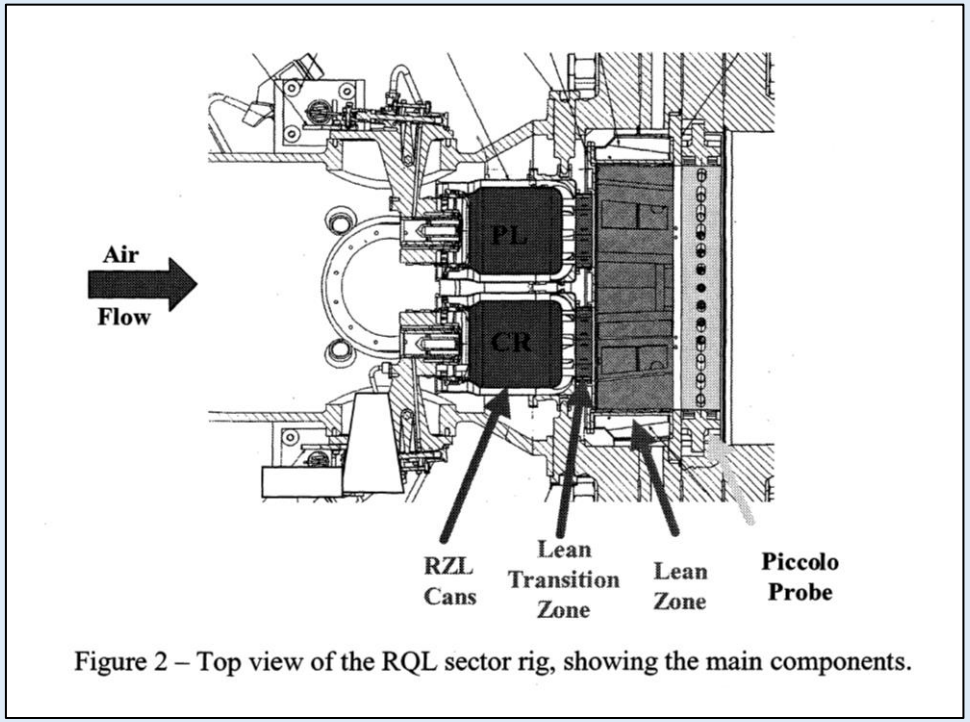


Figure 2 – Top view of the RQL sector rig, showing the main components.

CMC to Metallic Component Attachment Literature

- **It appears that currently the best source of "*open*" information on attachment concepts is found in patents. Thus, U.S. patents are being examined.**

U.S. Patent Apr. 4, 2000 Sheet 4 of 7 6,045,310

"Miller Fastener"

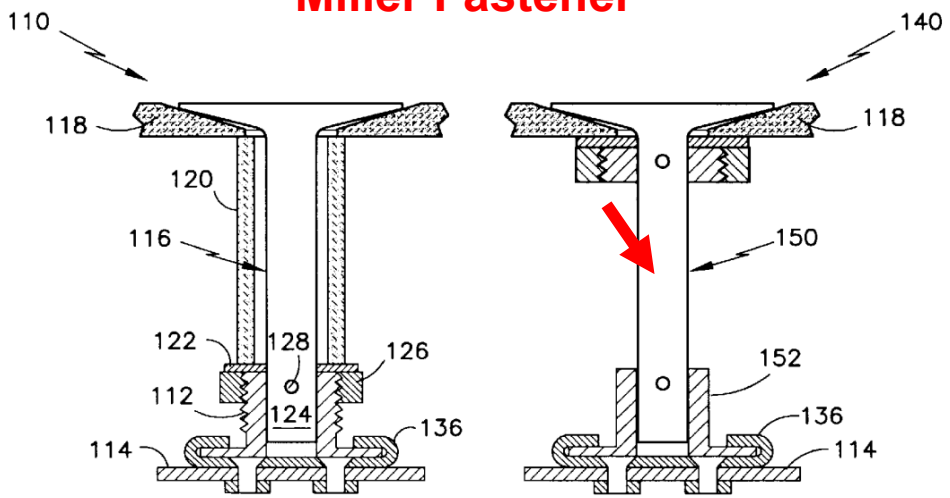


FIG.5A

U.S. Patent Mar. 8, 2022 Sheet 1 of 3 US 11,268,389 B2

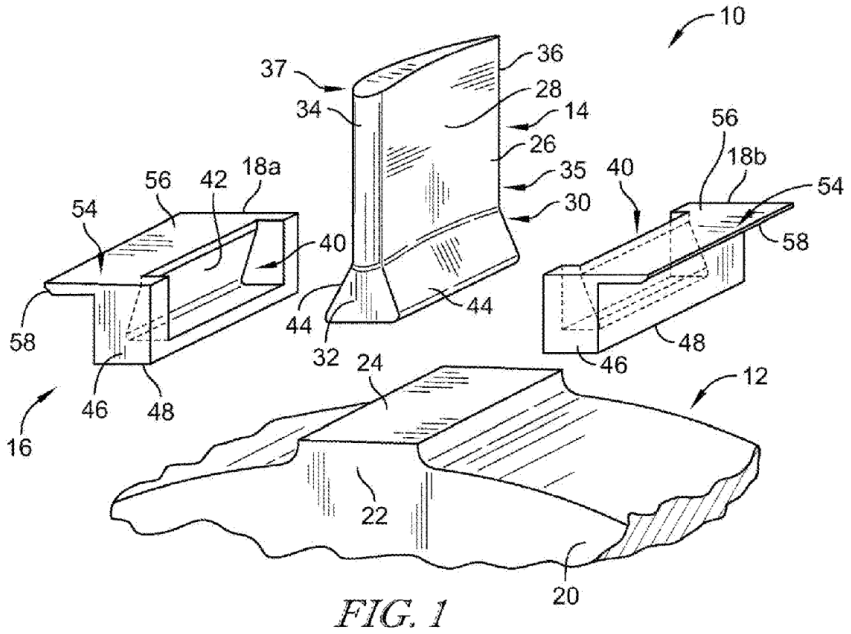


FIG. 1

- **The patents provide informative diagrams and information (solutions to issues).**

Selected U.S. Patents for Attaching CMC Components to Metallic Components

(Four of These are Reviewed in This Presentation)

U.S. Patent Number	Date	Title	Assignee	Article
6,045,310	Apr. 4, 2000	COMPOSITE FASTENER FOR USE IN HIGH TEMPERATURE ENVIRONMENTS	United Technologies Corporation	CMC Fastener
6,397,603 B1	Jun. 4, 2002	COMBUSTOR HAVING A CERAMIC MATRIX COMPOSITE LINER	The USA as represented by the Secretary of the Air Force	Combustor
6,884,026 B2	Apr. 26, 2005	TURBINE ENGINE SHROUD ASSEMBLY INCLUDING AXIALLY FLOATING SHROUD SEGMENT	General Electric Company,	HPT Shrouds
6,942,203 B2	Sep. 13, 2005	SPRING MASS DAMPER SYSTEM FOR TURBINE SHROUDS	General Electric Company,	HPT Shrouds
7,044,709 B2	May 16, 2006	METHODS AND APPARATUS FOR COUPLNG CERAMIC MATRIX COMPOSITE TURBINE COMPONENTS	General Electric Company	HPT Shrouds
7.546,743 B2	Jun. 16, 2009	BOLTING CONFIGURATION FOR JOINING CERAMC COMBUSTOR LINER TO METAL MOUNTING ATTACHMENTS	General Electric Company	Combustor
7,648,336 B2	Jan. 19, 2010	APPARATUS AND METHOD FOR ASSEMBLING A GAS TURBINE STATOR	General Electric Company	Stator/Vane
7,722,317 B2	May 25, 2010	CMC TO METAL ATTACHMENT MECHANISM	Siemens Energy, Inc.	CMC Wall/Metal Wall
7,874,059 B2	Jan. 25, 2011	ATTACHMENT FOR CERAMIC MATRIX COMPOSITE COMPONENT	Siemens Energy, Inc.	Attachment
8,061,977 B2	Nov. 22, 2011	CERAMIC MATRIX COMPOSITE ATTACHMENT APPARATUS AND METHOD	Siemens Energy, Inc.	Attachment
8,556,531 B1	Oct. 15, 2013	SIMPLE CMC FASTENING SYSTEM	United Technologies Corporation	CMC Fastening System
8,739,547 B2	Jun. 3, 2014	GAS TURBINE ENGINE JOINT HAVING A METALLIC MEMBER, A CMC MEMBER, AND A CERAMIC KEY	United Technologies Corporation	Attachment
9,500,083 B2	Nov. 22, 2016	APPARATUS AND METHOD TO REDUCE WEAR AND FRICTION BETWEEN CMC-TO-METAL ATTACHMENT AND INTERFACE	U.S. Department of Energy, Washington, DC (US)	Blade Attachment
9,546,557 B2	Jan. 17, 2017	NOZZLE, A NOZZLE HANGER, AND A CERAMC TO METAL ATTACHMENT SYSTEM	General Electric Company	Nozzles
10,458,260 B2	Oct. 29 , 2019	NOZZLE AIRFOIL DECOUPLED FROM AND ATTACHED OUTSIDE OF FLOW PATH BOUNDARY	General Electric Company	Nozzles
10,683,770 B2	Jun . 16 , 2020	TURBINE SHROUD ASSEMBLY HAVING CERAMIC MATRIX COMPOSITE TRACK SEGMENTS WITH METALLIC ATTACHMENT FEATURES	Rolls-Royce North American Technologies Inc., Rolls-Royce Corporation	HPT Shrouds
10,746,054 B2	Aug . 18 , 2020	TURBINE SHROUD WITH MOVABLE ATTACHMENT FEATURES	Rolls-Royce North American Technologies Inc., Rolls-Royce Corporation	HPT Shrouds
10,753,232 B2	Aug. 25 , 2020	ASSEMBLIES AND METHODS FOR COOLING FLOWPATH SUPPORT STRUCTURE AND FLOWPATH COMPONENTS	General Electric Company	Cooling Retention Assemblies
11,268,389 B2	Mar. 8 , 2022	BLISK BONDED CMC AIRFOIL HAVING ATTACHMENT	Rolls-Royce North American Technologies Inc., Rolls-Royce Corporation	Blade Attachment

Basic Attachment Issues, Requirements, and Challenges

Attachment feature designs are influenced by:

- **the operating temperature of the CMC component**
- **the operating environment of the attachment feature**
- **the load-carrying capability required**
- **the need to allow growth of both articles (CMC, metal) due to thermal expansion (CTE mismatch concern).**
- **desire to minimize weight but maximize the durability and reliability of the attachment**
- **assembly and disassembly requirements**
- **maintenance and cost considerations, etc.**

Attachment Requirements and Challenges

- **The design of attachment features is challenging.**
- **Thus, various CMC / Metallic component attachment schemes have been devised for initial use in test rigs, and then further matured for use in aircraft and ground-based turbine engines.**
- **All hardware must perform within the material design allowables.**
- **CMC components operate at a higher temperature than the metallic component, and the attachment feature must operate within a suitable temperature range. This can be accomplished by placing the attachment region in a lower T / cooled region of the engine.**
- **The attachment article needs to maintain the position of the CMC component while accommodating thermal expansion and contraction during engine warmup and cooldown. This can be addressed with gaps, flexible metallic hardware, and seals.**

Attachment Issues (Continued)

More general concerns about CMC to metallic interfaces

- Vibration damage: wear / rubbing / fretting of metallic fasteners by hard CMCs (SiC/SiC, Ox/Ox)
- Damage to attachment features or CMC component resulting from chemical reaction or diffusion (e.g., nickel, iron, etc. into the CMC)
- Oxidation, fatigue, or creep of metallic fasteners / hardware attached to CMCs at temperatures exceeding the metallic material's maximum use temperature
- Use of seals / thermal barriers between CMC and metallic fastening systems / hardware to keep metallic materials below their maximum use temperature
- Ensure any EBC (environmental barrier coating) on a SiC/SiC CMC is not degraded by a metallic fastening / positioning system
- Need for introducing holes / slots into the CMC component to allow attachment? Potential stress concentrator or a pathway for oxidation
- Need to contain pressure?

Discussion of Selected U.S. Patents for Attaching CMC Components to Metallic Components: CMC Blades Example

US Patent 9,500,083 B2

9,500,083 B2	Nov. 22, 2016	APPARATUS AND METHOD TO REDUCE WEAR AND FRICTION BETWEEN CMC-TO-METAL ATTACHMENT AND INTERFACE

- CMC blade inserted into metal disk dovetail slot.
- Rotating part. Airfoil high-frequency vibration results in what is commonly known as fretting wear.
- Intent: reduce wear and friction between metal and CMC components (wear of metal by hard CMC at operating T).
- High contact stresses can damage CMC (matrix cracking).
- Includes a metal layer (Ni, Co-based alloys, etc.) configured for insertion between CMC and metal components. Can be used in combustor applications, with fir tree root, etc.
- The metal layer (62) is compliant relative to asperities of the surface interface of the CMC component.
- Coefficient of friction between the surface interface of CMC component and the metal component is about 1.0 or less.
- Symmetrical one-piece interface layer resists motion.
- Could use dry film lubricant (76) on layer surface

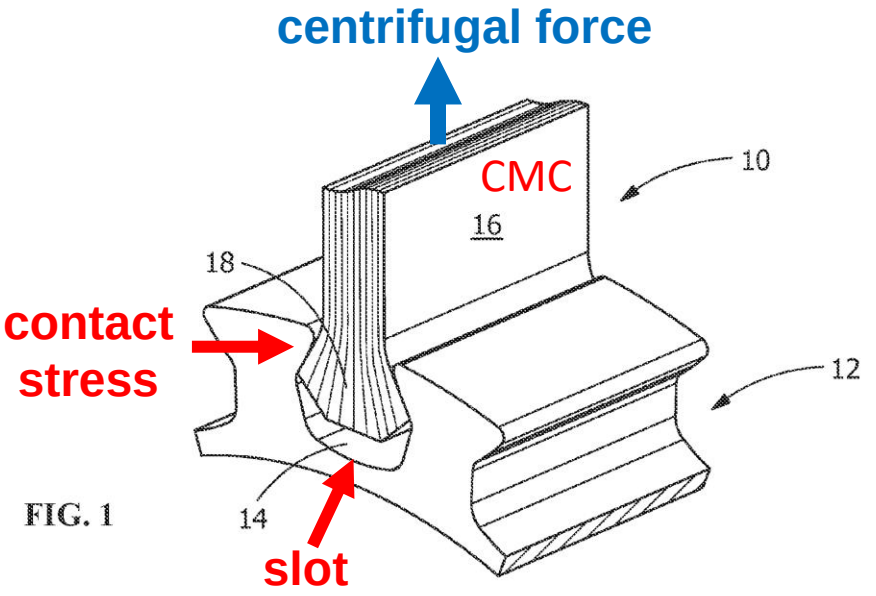


FIG. 1

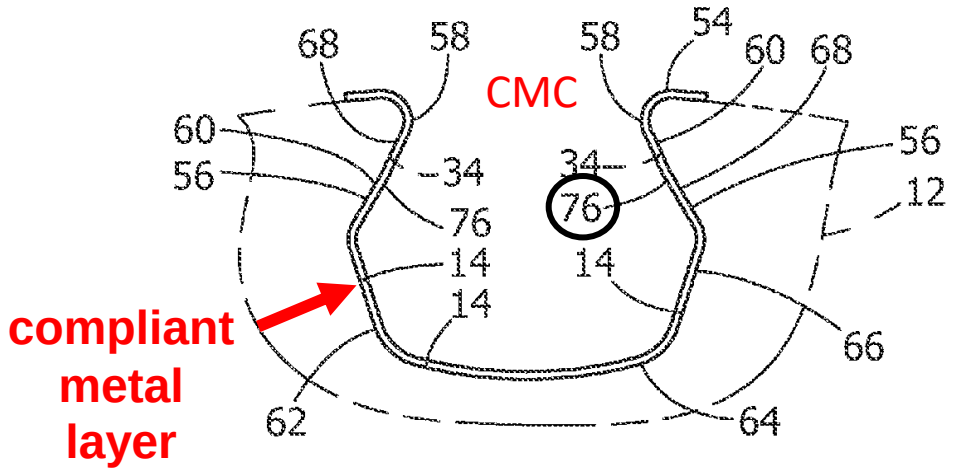


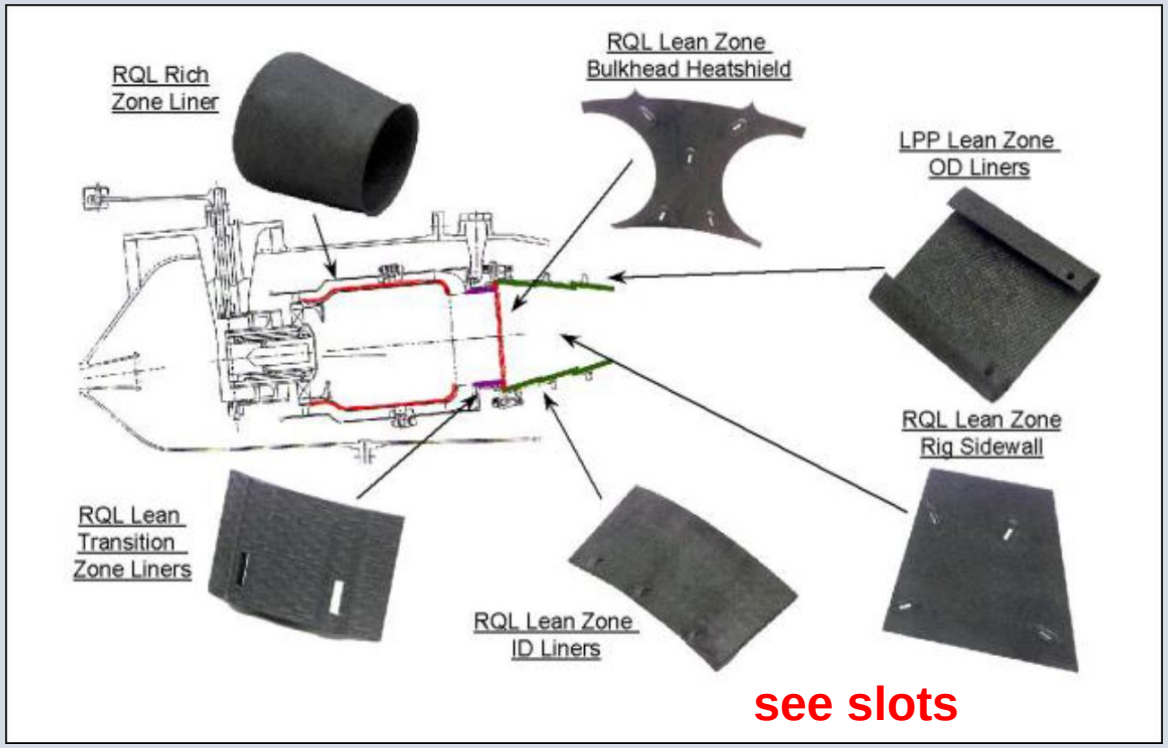
FIG. 5

Discussion of Selected U.S. Patents for Attaching CMC Components to Metallic Components: *Miller Fastener for High T Connections*

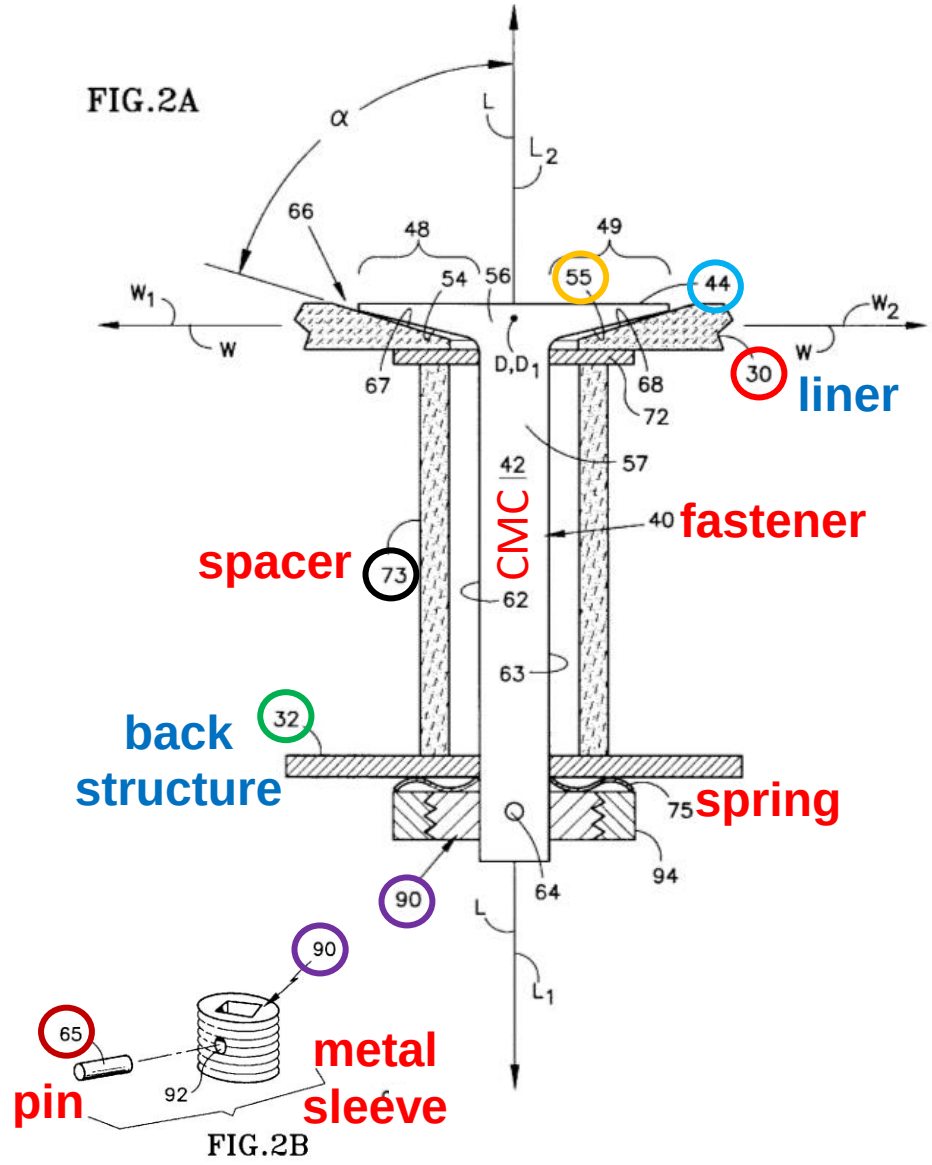
US Patent 6,045,310

6,045,310	Apr. 4, 2000	COMPOSITE FASTENER FOR USE IN HIGH TEMPERATURE ENVIRONMENTS

- **FIG. 2A: cross section view of a CMC fastening tab (40) that is placed in a machined slot in a CMC liner (30).**
- **The tab is machined from a CMC panel. The "head" (44) on the tab can have different configurations. Loading surface (55).**
- **Pin (65) transmits load to and from the shank (42).**



Ref. 16



Discussion of Selected U.S. Patents for Attaching CMC Components to Metallic Components: CMC Combustor Example

US Patent 7,546,743 B2

7.546,743 B2	Jun. 16, 2009	BOLTING CONFIGURATION FOR JOINING CERAMC COMBUSTOR LINER TO METAL MOUNTING ATTACHMENTS

- Describes an attachment system for securing a CMC combustor liner (16, 18) to metal mounting attachments.
- Combustor liner interfaces with metallic hardware of significantly higher strength and higher thermal expansion characteristics. Hula seal: centering liner. (26)
- Forward end of the liner is attached to an annular inner ring fitted over the liner. Specially-designed fasteners (50) pass through holes in the CMC liner and aligned holes in radially compliant, circumferentially spaced spring (30) fingers projecting from solid hoop portion of inner ring.
- The inner ring (20) is attached to a radially outer ring (22) by circumferentially spaced radial struts (52). The assembly is mounted so as to float with both axial and radial motion permitted to a limited degree.
- Gaps (56, 58, 60) allow a limited degree of float.
- Bolted joint is executed in a cooled, low stress area of the CMC liner at T within the metallic material limitations.

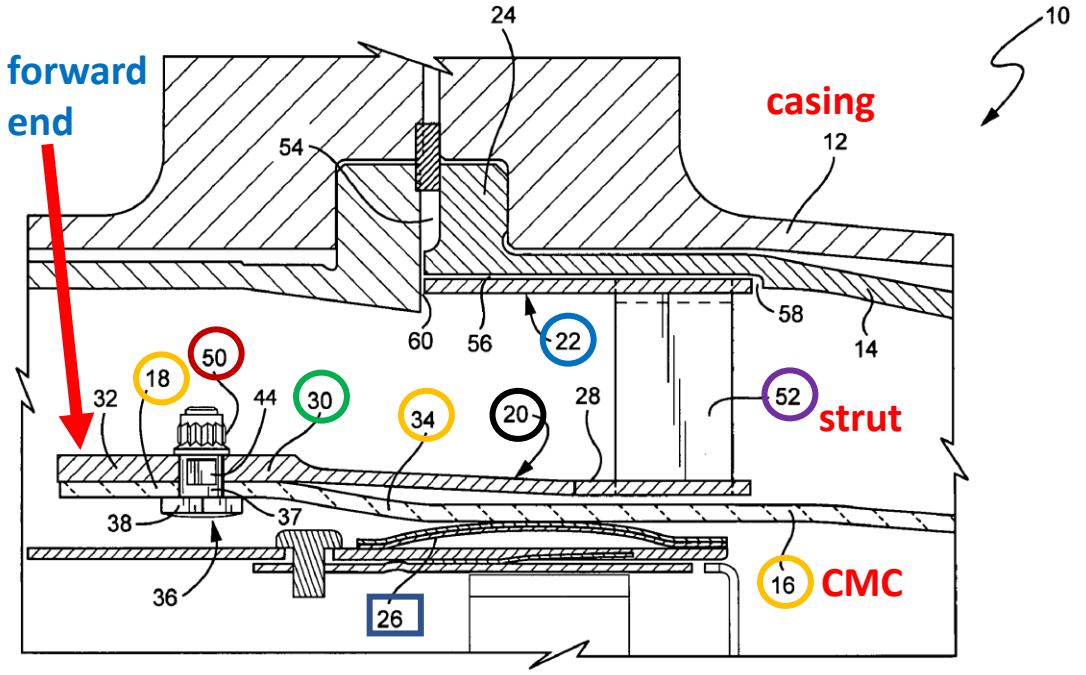


Fig. 1

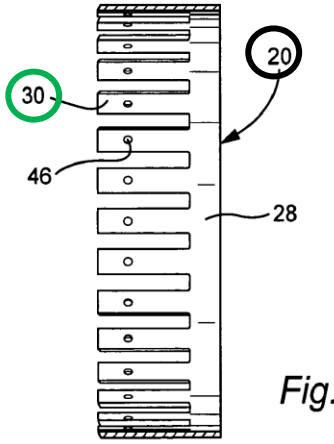


Fig. 3

inner attachment ring

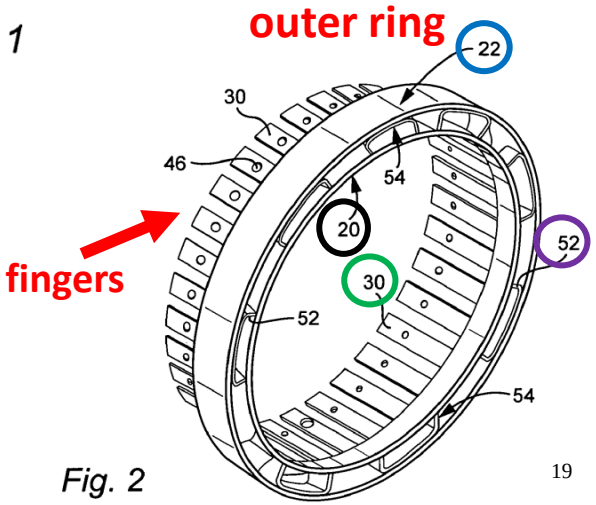


Fig. 2

Discussion of Selected U.S. Patent for Attaching CMC Components to CMC or Metallic Components: General Wall to Wall Connection

US Patent 8,556,531 B1

8,556,531 B1	Oct. 15, 2013	SIMPLE CMC FASTENING SYSTEM

- **Invention provides a simple CMC fastening system that connects CMCs to a non-CMC component (or CMC article).**
- **The system has a detachable subassembly bracket that has a slotted configuration with holes.**
- **Fasteners (flare end rivets (78)) are placed through the holes to hold the bracket in place.**
- **One end of the bracket is secured to the articles via the fasteners and the other end is secured to a non-CMC component.**
- **Belleville washers (74, 76) or shims may be used on one or both sides of the articles to maintain a tight fit during engine operation. Springs could also be used.**
- **Leaf spring (16) to lessen vibration effects.**

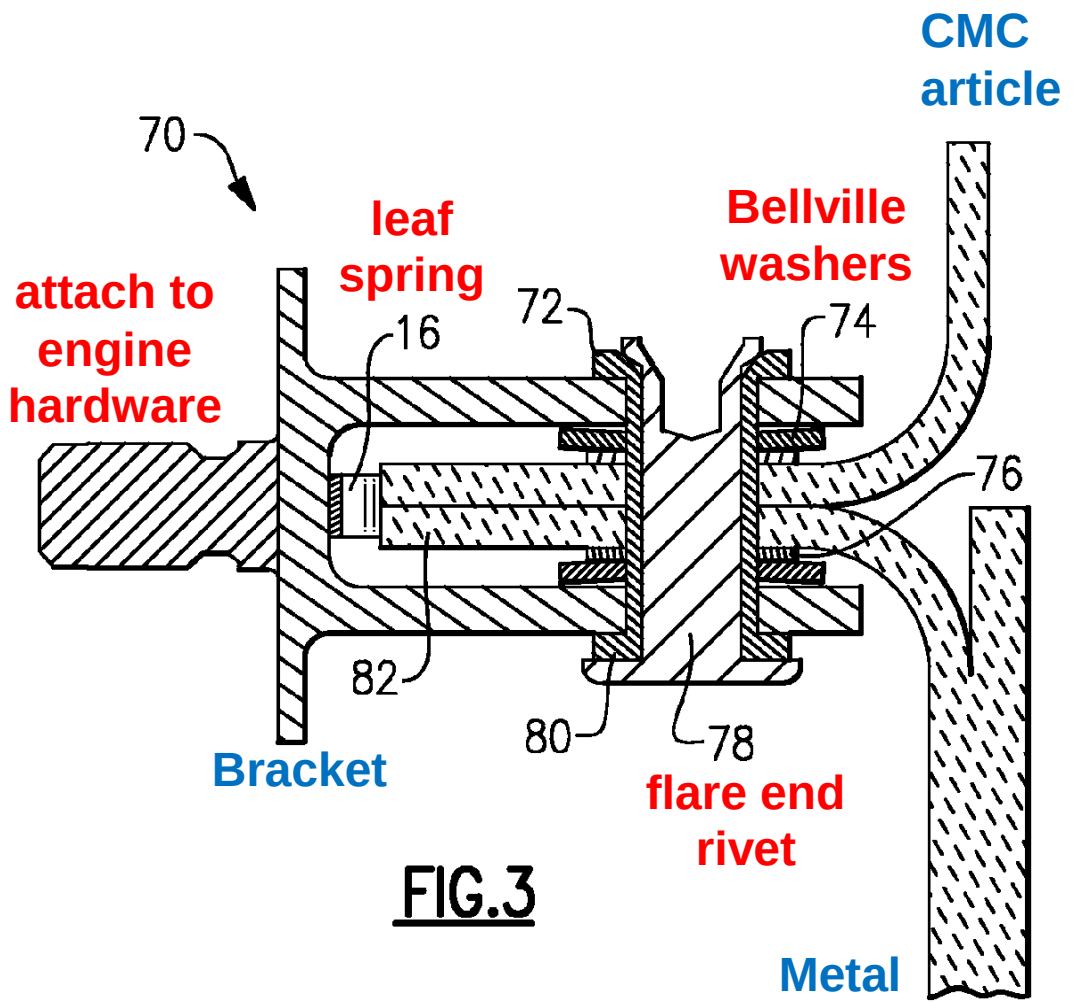
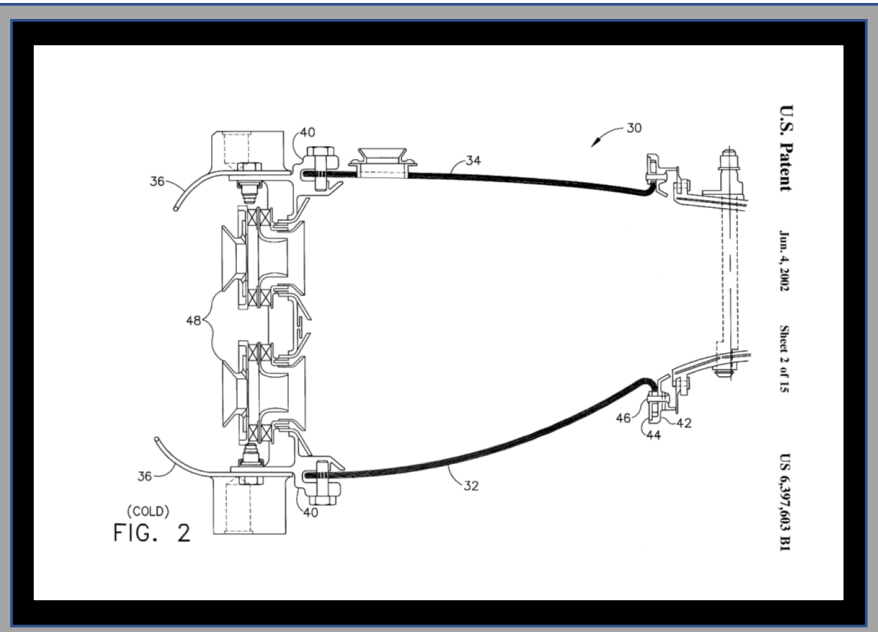
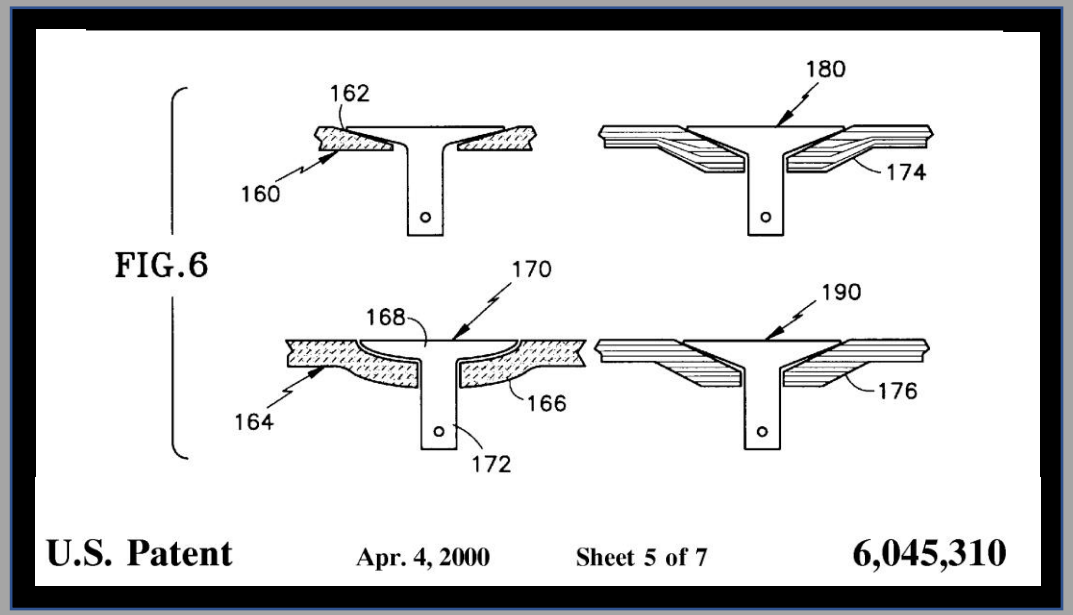


FIG.3

Future Work: Documenting Results of Assessing U.S. Patents and Attachment Articles and Getting Further Input From Others

- Finish reviewing selected patents. Results from assessing U.S. Patents and attachment articles / reports will be summarized.
- Contractor reports (unlimited rights) submitted following NASA HyTEC Phase I CMC efforts will provide additional useful information.
- OEM engineers will be requested to help improve the content of the chapter that is prepared for CMH-17 Vol 5.
- Please contact me if you have useful articles / suggestions for content.

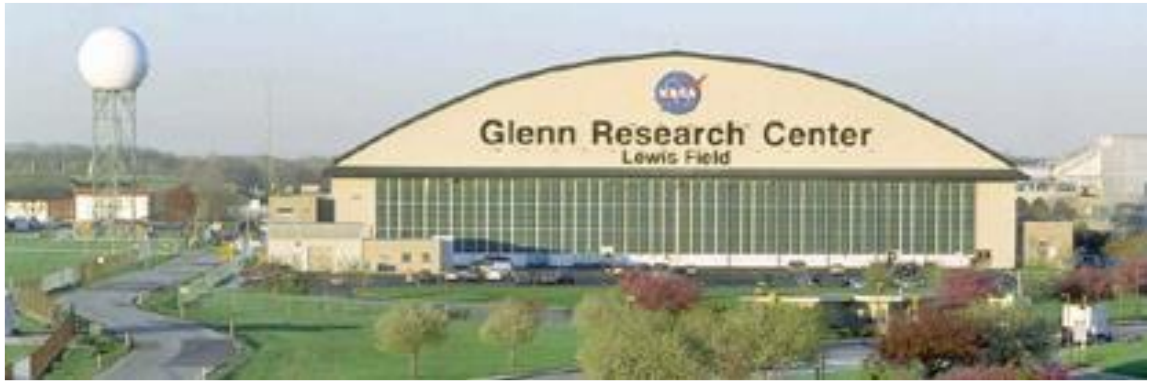




Acknowledgements

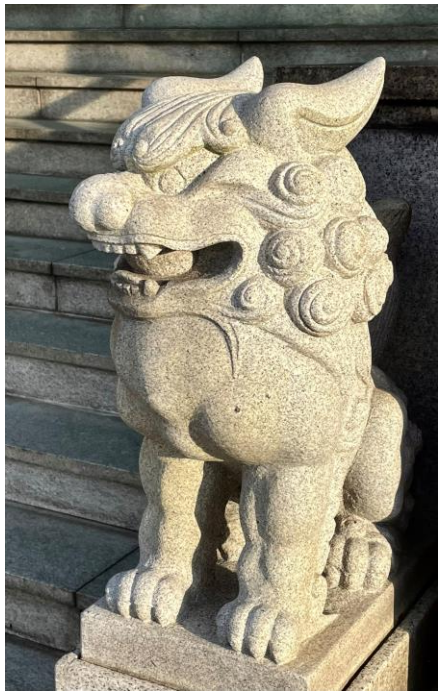
Travel funding provided by NASA HyTEC

The Hybrid Thermally Efficient Core (HyTEC) Project will accelerate development of high power-density core advanced turbine engine technologies in collaboration with industry.



Assistance from Mike Verrilli (GEA) and Leanne Lehman (Boeing Corp.) in initiating this effort. Will work with them on a document summarizing the results of the study.

Thanks to the HT-CMC 11 Organizers for their efforts



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