HYPERSO NIC RESEARCH VEHICLES
PURPOSE:

"... To separate real from imagined problems & to make known the overlooked and unappreciated problems"

H. Dryden October 1956

- FOCUS & STIMULATE TECHNOLOGICAL DEVELOPMENT TOWARDS POSSIBLE/PROBABLE SYSTEMS OF THE FUTURE

- VALIDATE AND/OR DEMONSTRATE SIGNIFICANTLY CRITICAL TECHNOLOGIES
X-15 IMAGINED PROBLEMS

• ASYMMETRICAL WING COOKIE SHEET DEFLECTION DURING HEAT-UP OF RE-ENTRY

• FLIGHT STABILITY & CONTROL BEING OTHER THAN THAT INDICATED IN LANGLEY 11-INCH HYPersonic TUNNEL WITH 11-INCH MODEL

• UNSATISFACTORY LANDING CAPABILITY WITH LOW L/D UNPOWERED CHARACTERISTICS

• UNCOMPENSATABLE ROLL-OFF DURING B-52 LAUNCH

• UNSATISFACTORY STRUCTURAL INTEGRITY BETWEEN COLD LO₂ TANKS & WARM INSTRUMENTATION BAY DUE TO THERMAL STRESSES & DEFLECTION
X-15 OVERLOOKED - UNAPPRECIATED PROBLEMS

- WINDSHIELD GLASS RETENTION & PERFORMANCE
- WING LEADING EDGE SLOT AERO-HEATING EFFECTS
- SIDE FAIRING THERMAL BUCKLING
- AUXILIARY POWER UNIT LUBRICATION IN RARIFIED ATMOSPHERE
- NOSE GEAR SHOCK ABSORPTION UPON RAPID EXTENSION - OIL FOAM
- B-52 FLAP CUT-OUT ACOUSTICS
- FLIGHT CONTROL AT HIGH g'S
- AIRFRAME - GYRO DYNAMIC COUPLING PRIOR TO RE-ENTRY
- CONFIGURATION EFFECTS ON LATERAL-DIRECTIONAL DYNAMIC STABILITY
METHODOLOGY FOR DEFINING HYPersonic research VEHICLES

- Identify possible-probable hypersonic systems
- Identify significant and/or pacing technologies
- Identify their appropriate speeds, altitudes, temperature etc.
- Identify their test time or time history requirements
- Identify their significant size requirements
- Integrate these technologies into a vehicle, or "flying-facility" carrier system
- Identify the launching system, air launch or ground take-off & its operational environment
- Cost the "flying-facility", the launch system, the operational system & the phased technologies
- Re-cost, reiterate & reselect
- Final selection of technologies, research airplane, operational system
OVERALL PROGRAM CRITERIA

- COST-EFFECTIVE TECHNOLOGY ELEMENT SELECTIONS
- APPROPRIATE FUNDING FOR SYSTEM DEVELOPMENT & TO FIRST FLIGHT
- EARLY SIGNIFICANT FLIGHT RESULTS & CONTINUING PHASED FLIGHT RESULTS
- CONTROLLED ANNUAL FUNDING REQUIREMENTS
- UTILIZE ENGINEERING "SPIN-OFFS" FROM OTHER PROGRAMS-e.g., SHUTTLE, RL-10 ETC
- DEVELOP RESEARCH VEHICLE AS "FLYING-FACILITY", WIND TUNNEL MODEL ADAPTABILITY, "BOILERPLATE" FEATURES AS APPROPRIATE
- IMPLEMENT COST-PERFORMANCE TRADE-OFFS FOR VEHICLE, TECHNOLOGIES & SUBSYSTEMS
POSSIBLE/PROBABLE HYPERSONIC SYSTEMS

ALTITUDE (1000 FT)

400
300
200
100

VELOCITY (1000 FT/SEC)

AIRBREATING LAUNCH VEHICLES
HYPERSONIC TRANSPORTS

MILITARY SYSTEMS
RE-ENTRY RE-ORBIT

MILITARY SYSTEMS
MANNSD-UNMANNED
INTERCEPTORS

Space Division
North American Rockwell

82PD114309
POSSIBLE SYSTEMS ENVIRONMENT & PRINCIPAL CHARACTERISTICS

PRINCIPAL PROPULSION SYSTEMS/FUELS

ALTITUDE (1000 FT)

MACH NUMBER

SUB-RAMJET, HEAVY HYDROCARBONS

SUB-RAMJET, HYDROCARBONS

DUAL MODE SUB/SUP. RAMJET

SUBSONIC RAMJETS, LH₂

EJECTOR RAMJETS, METHANE FUELS

GAS TURBINES, RAMJETS, METHANE FUELS

GAS TURBINE - ENDOThERMIC FUELS

SHUTTLE GLOBOCOSMOPHILUS
MATERIAL APPLICATION TRENDS FOR SIGNIFICANT AREAS OF REPRESENTATIVE VEHICLES
PRELIMINARY H.R.A. REQUIREMENTS
PROPULSION SYSTEMS - FUELS

- RECOMMEND M3.5+ ENDOOTHERMIC GAS TURBINES - FUELS RESEARCH TO YF-12 TYPE AIRCRAFT WITH HEAT PROTECTION

- INCLUDE DESIGN CONSIDERATIONS FOR GAS TURBINES, SUBSONIC JETS, & EJECTOR RAMJETS WITH METHANE

- INCLUDE DESIGN CONSIDERATIONS FOR SUBSONIC RAMJETS WITH HYDROCARBON & HEAVY HYDROCARBON FUELS

- INCLUDE DESIGN CONSIDERATIONS FOR SUBSONIC, SUPERSONIC & DUAL-MODE RAMJETS WITH HYDROGEN FUEL.
<table>
<thead>
<tr>
<th>FUEL</th>
<th>HEAT OF COMBUSTION (BTU'S/LB)</th>
<th>HEAT SINK (BTU'S/LB)</th>
<th>DENSITY (LB/FT³)</th>
<th>HEAT SINK LIMIT TEMP (DEG F)</th>
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AT 1.8$/LB
AT 2$/LB
AT 10$/LB (AT 30$/LB)
FUEL CONSIDERATIONS

CRUISE EFFICIENCY COMPARISON

COMPARISON OF DIRECT OPERATING COST

METHANE COULD LOWER DIRECT OPERATING COST

DOC FOR AIRCRAFT CRUISING AT MACH 10

- PRESENT HST STUDIES INDICATE SYSTEM IS FEASIBLE AT 8¢ /LB LH₂ BUT NOT AT 15 TO 30¢ /LB
- RANGE POTENTIAL & ECONOMICS SUGGEST SIGNIFICANT EVALUATION OF METHANE

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82PD114315
PROPULSION SYSTEMS—FUELS RECOMMENDATIONS

• ACQUIRE UPDATED DEVELOPMENT COST AND SCHEDULES

  • P & W J-58 ADAPTED TO METHANE & HYDROGEN FUELS & AS RELATED TO DESIGN MACH NUMBER

  • MARQUARDT E.R.J. & S.E.R.J. ENGINES FOR METHANE & HYDROGEN FUELS

  • AI RESEARCH H.R.E. FLIGHT-WEIGHT ENGINE WITH HYDROGEN FUEL

USING ONLY THAT QUALIFICATION APPROPRIATE TO H.R.A. NEEDS AND FLIGHT TEST APPROACH
SCRAMJET INTEGRATION

AIRFRAME - PROPULSION COMPATIBILITY
INTEGRATED PERFORMANCE
WEIGHTS & VOLUMES
DYNAMIC EFFECTS, ACCELERATION, DECELERATION
ANGLE OF ATTACK CAPABILITIES
ANGLE OF YAW CAPABILITIES
OPERATIONAL CHARACTERISTICS

TRADE-OFFS

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North American Rockwell

82PD114317
STRUCTURAL MATERIALS APPLICATIONS
RECOMMENDATIONS

INCLUDE DESIGN CONSIDERATIONS FOR INCORPORATING SIGNIFICANTLY LARGE PORTIONS OF THE VEHICLE OR TEST PANELS OF:

- INCONEL 718
- RENE' 41
- HAYNES 25
- TD-NiCr
- ACTIVELY COOLED
  - ALUMINUM
  - TITANIUM
  - RENE' 41
CURRENT COST STUDY IMPLICATIONS
"HYFACS" CR 114322

<table>
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<th>M6 TURBORAMJET MILLIONS $</th>
<th>M12 ROCKET MILLIONS $</th>
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<tr>
<td>RDT&amp;E</td>
<td>212 (43.3%)</td>
<td>126 (35.9%)</td>
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<td>INVESTMENT</td>
<td>186 (38.3%)</td>
<td>137 (39.1%)</td>
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<tr>
<td>OPERATING</td>
<td>92 (18.5%)</td>
<td>88 (25.0%)</td>
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<td>490</td>
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- RE-EVALUATE INVESTMENT REQUIREMENTS TOWARD PROGRAM COST REDUCTIONS FOR ONLY ESSENTIAL DEVELOPMENT TASKS. REDIRECT COSTS INTO AIR VEHICLE DEVELOPMENT & VERSATILITY

- RE-EVALUATE OPERATING COSTS FOR MAXIMUM FLIGHT EVALUATIONS

\[
\frac{88}{\text{LILLION}} = \frac{200}{5}\text{ FLIGHTS/FLIGHT, } \frac{200}{5} \text{ FLIGHTS/FLIGHT} = 40 \text{ FLIGHTS/YEAR}
\]
X-15 PROGRAM REVIEW

- DESIGN COMPETITION
- CONTRACT AWARD
- DGI BOARD
- DRAWING RELEASE
- ROLL OUT, NO. 1
- FIRST GLIDE, NO. 1
- FIRST POWERED NO. 2 LR-11
- FIRST FLIGHT LR-09
  - 320,000 ft
  - 1322 F, 20.22 psf
  - 1114 miles, Mach 6.0
  - 354,000 ft

- DESIGN & FABRICATION
- CHECKOUT
- LR-11 FLIGHT TEST
- LR-99 FLIGHT TEST
- ADDITIONAL FOLLOW-ON FLIGHT RESEARCH
SCHEDULED EXPERIMENTS THROUGH 1968

- Induced Turbulence
- Micrometeorite Atmos Density, Sky Brightness
- Infrared Scanner
- X-15 UV Measurements
- Vapor Cycle Cooling
- Advanced Structures & Aerodynamic Research
- UV Stellar Photography
- Hycon Camera
- Deceleration Device
- Air-Breathing Propulsion
- UV Plume, Infrared Exhaust Signature
- Aerodynamic Noise
- Advanced Integrated Data System
H.R.A. SYSTEM DEFINITION DRIVERS

ALTITUDE (1000 FT)

MACH NUMBER

FLIGHT DYNAMIC PRESSURES - PSF

H.R.A. SYSTEMS

- DESIGN CRITERIA
- EXTERNAL SHAPE
- PROPULSION
- AIRBREATHING
- ROCKET
- STRUCTURES
- TANKAGE
- PROPELLANTS
- FLIGHT CONTROLS
- WINGS
- AVIONICS
- SUBSYSTEMS
- LAUNCH SYSTEMS
- GROUND SYSTEMS & OPERATION
- MANNED/UNMANNED

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82PD114323
OPERATIONAL EFFICIENCY - X-15

- EFFECT OF RELIABILITY & MAINTAINABILITY OF VEHICLE SYSTEMS - PROPULSION

AVERAGE TURNAROUND TIME (BASED ON AVERAGE OF SUCCESSIVE 5-FLIGHT GROUPS)

- TURNAROUND
- FLIGHT FREQUENCY
- FLIGHT RESEARCH PRODUCTIVITY

- LESS SOPHISTICATED ENGINE SYSTEM
- LOWER MACH NO. FLIGHTS
- W/O REACTION CONTROL SYSTEM

- MORE COMPLICATED ENGINE SYSTEM
- MORE ENGINE RUN-UP'S REQD
- RECOATING ENGINE NOZZLE
- HIGHER MACH NUMBER AND HIGHER ALTITUDE FLIGHTS

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North American Rockwell

82PD114325
EFFECT OF RELIABILITY & MAINTAINABILITY OF VEHICLE SUBSYSTEMS

SOURCES OF SCHEDULING DELAYS
(TO OCT. 10, 1961)

- APU AND FUEL SYSTEM
- ENGINE
- PROPULSION SYSTEM LESS ENGINE
- WEATHER
- HEAT AND VENT
- MISCELLANEOUS
- HYDRAULIC
- INERTIAL
- TELEMETRY
- BCS
- SAS
- ELECTRIC
- RADAR AND RADIO
- FLIGHT CONTROLS

PERCENT OF TOTAL DELAY TIME

SOURCES OF SCHEDULING DELAYS
SINCE XLR99 INSTALLATION (13 FLIGHTS)
(TO OCT. 13, 1961)

- ENGINE
- PROPULSION SYSTEM LESS ENGINE
- MISCELLANEOUS
- APU AND FUEL SYSTEM
- INERTIAL
- WEATHER
- SAS
- ELECTRICAL
- HEAT AND VENT
- TELEMETERING
- RADAR AND RADIO
- HYDRAULIC
- FLIGHT CONTROLS

PERCENT OF TOTAL DELAY TIME
SIGNIFICANT DESIGN CRITERIA FROM INITIAL H.R.A. REVIEW

- BASEPOINT PERFORMANCE REQUIREMENT AT M6 FOR 10 MIN & TRADE UP FOR M8, M10 CAPABILITIES

- PROVIDE FUELS TANKAGE VOLUME FOR JP FUELS, METHANE & HYDROGEN

- ACCOMMODATE JP RAMJETS, METHANE & LH2 ERJ & SERJ ENGINES

- UTILIZE RL-10 ROCKET ENGINES AS PRIMARY PROPULSION & TRADE-OFF FOR PERFORMANCE & CAPABILITIES OF LR-91 STORABLE ROCKET ENGINE

- INCORPORATE CAPABILITY TO ACCEPT SCRAMJET MODULES DURING THE FLIGHT TEST PHASE

- EVALUATE COST-EFFECTIVENESS OF GROUND TAKE-OFF & LANDING (WHEELS) VS AIR-LAUNCHED & SKIS FOR LANDING

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SIGNIFICANT DESIGN CRITERIA FROM INITIAL H.R.A. REVIEW (CONT)

• PROVIDE FOR VARIOUS TYPES OF STRUCTURE FOR FUSELAGE, WING & EMPENNAGE COMPONENTS

• CONSIDER UPPER FUSELAGE MODIFICATION CAPABILITY FOR LAUNCHING SECOND STAGE VEHICLE EXPERIMENTS

• DESIGN H.R.A. NO.'S 1 & 2 FOR HIGH-CONFIDENCE - LEVEL HOT STRUCTURES OF TITANIUM, INCONEL-718, RENE' 41, HAYNES-25, TD-NiCr, ETC., AS REQUIRED, & WITH GAS TURBINES, ERJ, SERJ ENGINES, AS SELECTED, & WITH APPROPRIATE FUELS & WITH OUTER STRUCTURE REMOVABILITY CONSIDERATIONS

• DESIGN H.R.A. NO. 3 FOR ROCKET/SCRAMJET PROPULSION SYSTEMS WITH ACTIVELY COOLED STRUCTURE DECOUPLED FROM THE TANKAGE - INSULATION FROM A LOAD-CARRYING FEATURE
FLIGHT TEST SCHEDULE PHASING

H.R.A. NO. 1
- HOT STRUCTURE
- SERJ PROPULSION
- JP FUELS
- METHANE FUEL

H.R.A. NO. 2
- HOT STRUCTURE
- LH₂ FUEL
- RL-10 PROPULSION

H.R.A. NO. 3
- ACT COOLED STRUCTURE
- LH₂
- RL-10 PROPULSION
- SCRAMJET PROPULSION

1 2 3 4 5 6 7 8

M = 2.5 M = 5.0 M = 5.0

M = 5.0 → 6.0

GROUND TAKE-OFF

M = 2.5 M = 5.0 M = 6.0

AIR LAUNCHED

M = 5.0

RL-10

M = 5.0 M = 6.0

RL-10 + SCRAMJET

M = 8.0

EXTERNAL TANKS
REUSABLE EXTERNAL INSULATION
HYPERSONIC RESEARCH AIRPLANE PROGRAM PHASING

M = 6.0 TECHNOLOGIES

PHASE A

PHASE B

DESIGN & FAB NO. 1 & 2

C/O

FLIGHT EVALUATIONS

M = 10.0 TECHNOLOGIES

DESIGN & FAB NO. 3

C/O

SCRAMJET PROPULSION

ACTIVELY COOLED STRUCTURE

REUSABLE INSULATION

FLIGHT

Space Division
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82PD114332
SIGNIFICANT TECHNOLOGIES

M6.0 TECHNOLOGIES

- PRELIMINARY DESIGN FOR M4.5 - M10 CONFIGURATION
- STRUCTURAL DESIGNS FOR M = 6.0
- INLET - PROPULSION SYSTEM - FUEL INSTALLATIONS
- ALTERNATE PROPELLANT TANKS
- M4.5 - M6.0 ACCOMMODATIONS FOR RADARS, SENSORS, ANTENNA, "HIDE", ELECTRONICS, FIRE CONTROL, ETC.
- WIND TUNNEL TESTING
- SUBSYSTEMS DESIGNS

M10.0 TECHNOLOGIES

- STRUCTURAL DESIGN INCLUDING ACTIVELY COOLED STRUCTURE
- REUSABLE SURFACE INSULATION
- PROPELLANT DISTRIBUTIONS SYSTEM: SCRAMJET STRUCTURE ROCKET ENGINES
# SYSTEMS ENGINEERING ANALYSIS PROGRAM

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<td>PHASE A</td>
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## INTEGRATED DESIGN
- REQMTS & TRADES
- CONCEPTUAL
- PRELIMINARY

## PROPULSION
- REQMTS & TRADES
- CONCEPTUAL
- PRELIMINARY
- GAS TURBINE
- RAMJETS
- SCRAMJETS
- ROCKET

## PROPELLANT TANKAGE
- REQMTS & TRADES
- CONCEPTUAL
- PRELIMINARY
- J.P. FUEL
- METHANE
- LO₂
- LH₂
- AUXILIARY (H₂O₂, He)

- SIMPLE CYLINDERS
- INTERSECTING CYLINDERS
- SIMPLE CONES
- INTERSECTING CONES

- ALUMINUM
- TITANIUM
- INSULATION
### Systems Engineering Analysis Program (Cont)

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<tr>
<th>Year</th>
<th>Phase A</th>
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<tr>
<td>CY 1972</td>
<td>PROPELLANT MANAGEMENT</td>
<td>STRUCTURES</td>
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<td>1973</td>
<td>REQMTS &amp; TRADES</td>
<td>CONCEPTUAL</td>
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<td>1974</td>
<td>C.G. CONTROL</td>
<td>PRIMARY</td>
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<td>1975</td>
<td>DISTRIBUTION SYSTEM (RL-10, SCRAMJET, STRUCTURE, DYNAMICS)</td>
<td>INSULATION</td>
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<td>1976</td>
<td>PURGE SYSTEMS</td>
<td>OUTER HEAT SHIELDS</td>
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<td>REMOVABILITY (FIELD BREAKS, ACCESS DOORS)</td>
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# Systems Engineering Analysis Program (Cont)

## Subsystems Requirements & Trades

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**Subsystems**
- Power, Electrical, Hydraulic
- Environmental Control System
- Flight Control Systems—Aerodynamic & Electronic
- Guidance System—Airborne—Ground
- Controls & Displays
- Avionics
- Instrumentation
- Telemetry
- Payloads Accommodations
- Pilot(s) Accommodations
- "Off-the-Shelf"

## Operations Requirements & Trades

**Operations**
- Basing, One vs Two
- Radars Tracking
- Ground Service Equipment
- AirLaunch—Ground Take-Off
- Weather Impacts
- Chase, Rescue
- Turnaround

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North American Rockwell

82PD114336
SYSTEMS ENGINEERING ANALYSIS PROGRAM (CONT)

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WIND TUNNEL TESTS
- CONFIGURATIONS
- WING GEOMETRY
- PROPULSION EFFECTS
- AERODYNAMIC HEATING

SCHEDULE/COSTS
- VEHICLE DESIGN
- FACILITIES
- OPERATIONS
- PHASING
SUPPLEMENTARY INFORMATION
CORRELATION OF PILOT RATINGS WITH \( C_{n\beta} - C_{l\beta} \) & ASSOCIATED RESPONSE MODES

**176 A UNAUGMENTED UNSTABLE MACH NO. = 14 \( \alpha = 34.5 \text{ DEG} \)**

**UNCOUPLERD ROLL & SPIRAL MODES**
- INCREASING ROLL DAMPING
- DECREASING SPIRAL MODE DAMPING

**BASELINE**
- **APPARENT CORRELATION WITH LATERAL-DIRECTIONAL RESPONSE MODES**
- \( C_{n\beta} \) PRIME DRIVER

\**C_{n\beta}** (PER DEG)

\**C_{l\beta}** (PER DEG)
BENEFITS OF HYPERSONIC RESEARCH AIRPLANES

• PROVIDE THE NECESSARY TECHNICAL & ECONOMIC INFORMATION, MOVING FROM STUDIES & ANALYSES TO APPROPRIATE SUB-SCALE FLIGHT HARDWARE EVALUATIONS SUCH THAT THE HYPERSONIC PROGRAMS OF THE FUTURE WILL BE ON AN APPROPRIATE BASIS FOR SUCCESS WHEN INITIATED

• NEXT GENERATION AIR-BREATHING LAUNCH SYSTEMS

• HIGH SUPERSONIC & HYPERSONIC TRANSPORTS

• HIGH SUPERSONIC & HYPERSONIC MILITARY SYSTEMS

• THE H.R.A.'S WILL ADDRESS THE POTENTIAL OF CONTINUING TO REDUCE THE COSTS OF PUTTING PAYLOADS INTO EARTH ORBIT; EVALUATING VARIOUS FUELS & THEIR COMPARATIVE ECONOMIES; & SUPERSONIC COMBUSTION RAMJETS & ITS COMPARATIVE PERFORMANCE, WEIGHTS & ECONOMIES
BENEFITS OF HYPERSONIC RESEARCH AIRPLANES (CONT)


- THE H.R.A.'S WILL ADDRESS THE REQUIREMENTS OF EVALUATING MILITARY TACTICS & POTENTIAL VEHICLE OPERATIONAL SUBSYSTEMS PRIOR TO COMMITMENT OF A FINAL SYSTEM
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