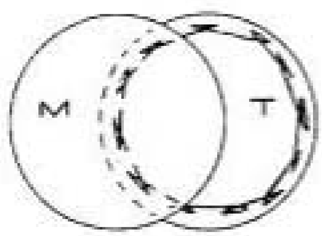
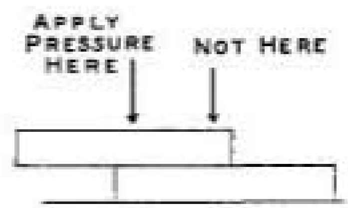
Lens & Mirror Making

- Best lenses and mirrors are both made by grinding the surface
- Start with a mirror or lens blank
- For mirrors only surface needs to be good
- Typical mirror want pyrex (eg BK7)
- Then need a tool blank – poorer glass & softer glass
- Place mirror on top tool
- Now add grinding compound (grit) between tool & mirror
- Grinding – moving the mirror over the tool with grit between)
- Grinding compound will make tool convex, mirror concave



a



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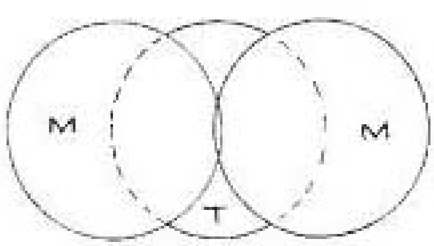
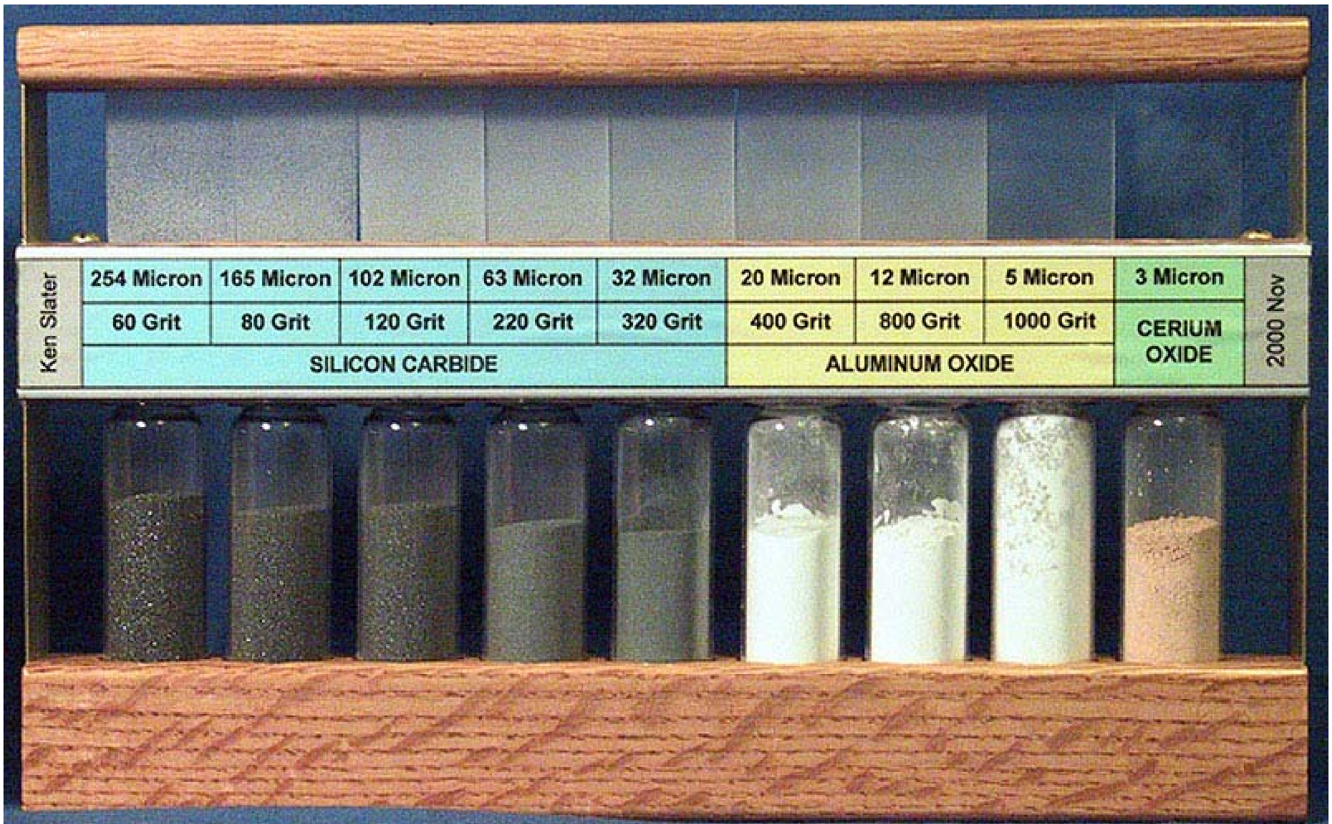


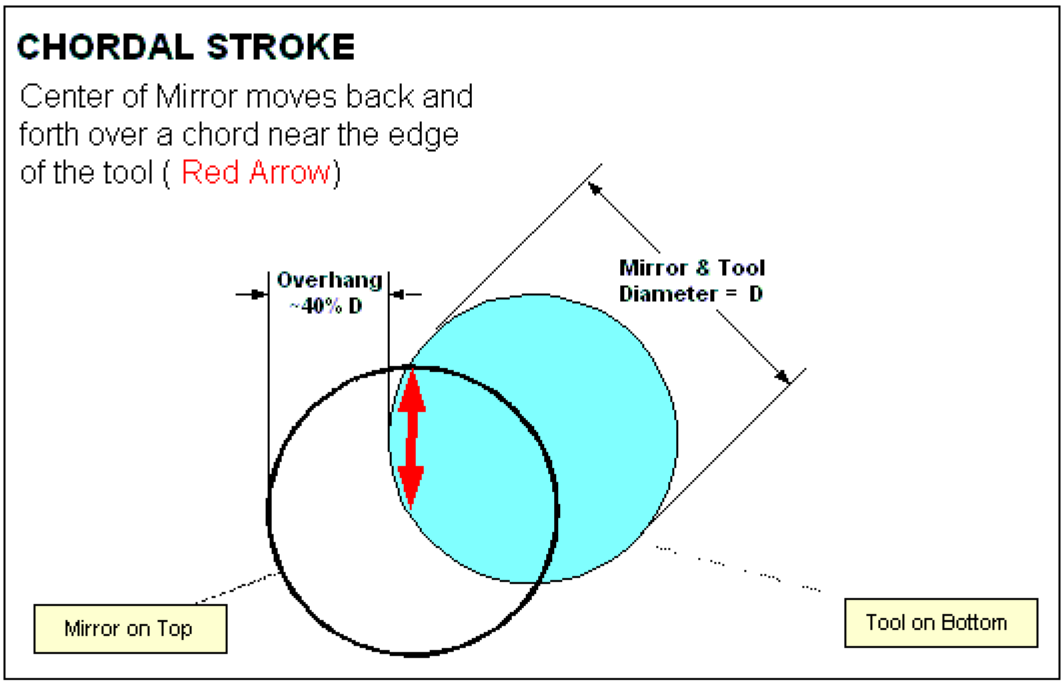
Grinding Compounds

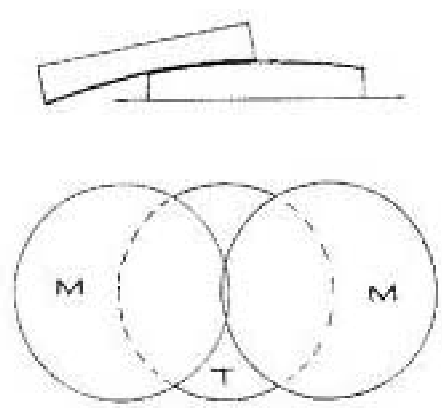
- Grinding compound is material much stronger than glass
- Made of fine powders, grit, in water solution
- Typical materials silicon carbide, aluminum oxide (sapphire)
- Start with largest grit
- Size is give as number of holes per 1 inch
- 60 grit ~ 254 microns
- Put grit in water to create grinding solution (paste)



Grinding Motion

- Move mirror back and forth over tool & grinding compound
- After number of strokes rotate mirror, tool in opposite direction
- Change position of stroke alternatively
- Eventually move fully around the mirror
- Grit removes material from both
- But tool edges wear down, while mirror center carved out

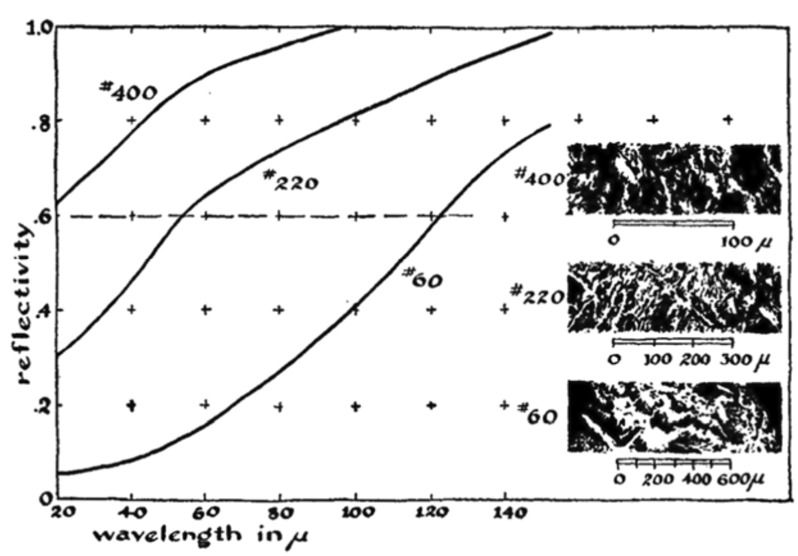




Progressive Correction

- 60 or 80 grit used to create the rough surface.
- Use simple depth measurement to roughly check
- Measurement or templet
- But rough grit leaves rough frosted surface
- Need to create smoother surface
- Now switch to finer grit 60 to 80 to 120 … 1000 grit
- 60 grit creates ~ 200 um holes – need to get to λ/4 at least
- Each grit removes damage of previous level

FIG. 13-3 Dependence of specular reflectivity on roughness.

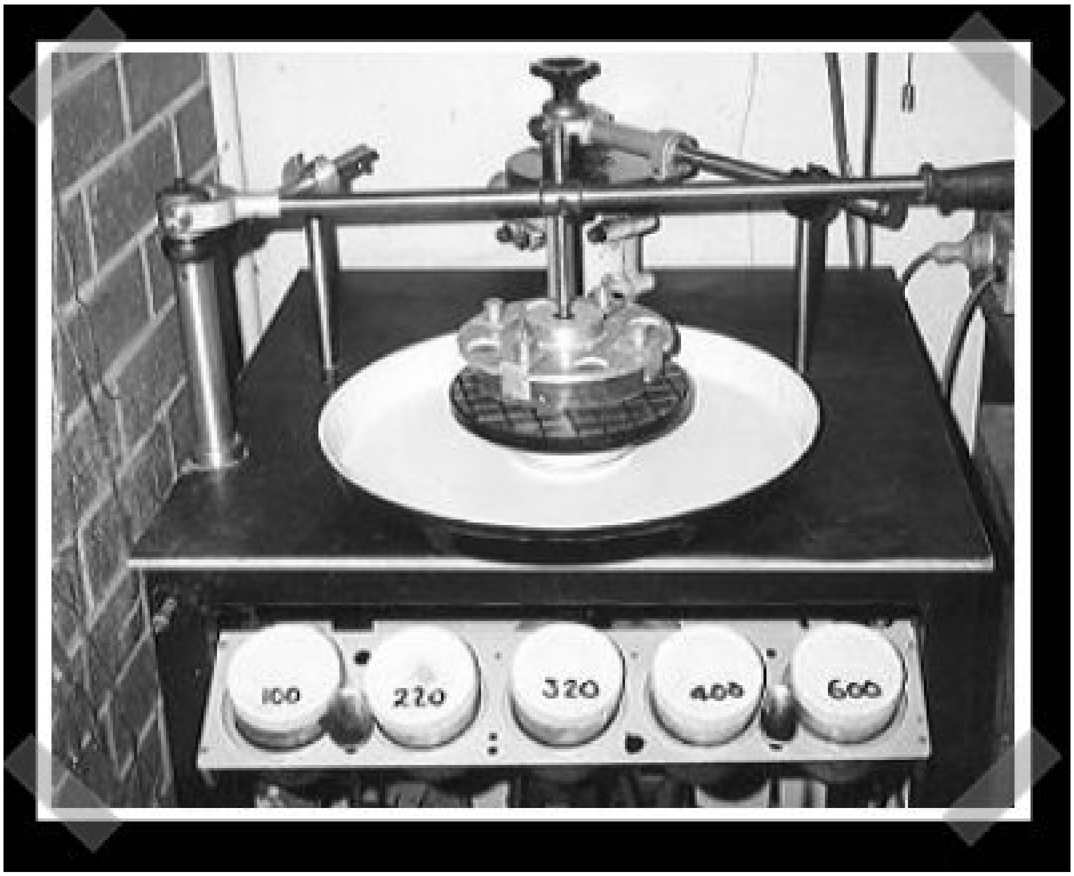


Polishing

- Need to get to $\lambda/4$ at least, $\lambda/8$ typical
- Now cover tool with a softer surface
- Use a pitch lap (or similar)
- Use a soft material, cast on surface, & cut groves in it
- Classic is pitch (from trees) heated and cast on surface.
- Then heat and let take shape of mirror
- Now apply a polishing compound – jeweller's rough is classic
- Polish until surface is mirror like & transparent

Grinding Machines

- Hand grinding takes several days
- Grinding machines designed to create exact same pattern
- Can adjust stroke, positions etc – auto rotates mirror and tool
- Simple machines cost few hundred



Figuring & Testing: Foucault Knife Edge test

- When mirror is near finished can start testing for shape (figuring)
- Simple test – wet mirror and see where it focuses light
- Gives rough focal length
- Now must tests to get the exact shape – parabolic etc.
- Most common Foucault Knife Edge test
- Place mirror on stand
- At focus place a pin hole light source (often laser now)
- Observe with knife edge (razor edge) to cut the beam

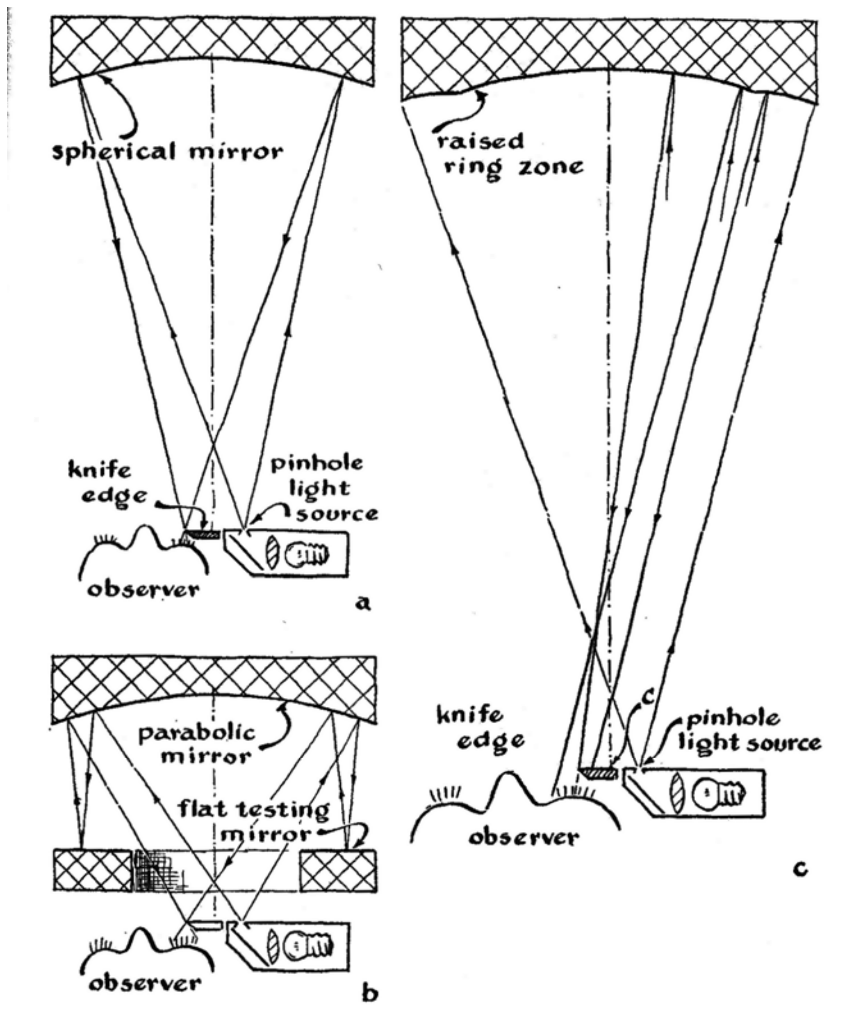
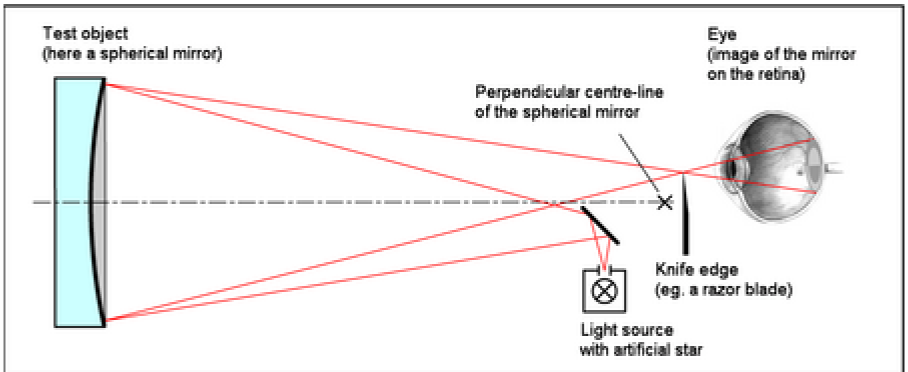
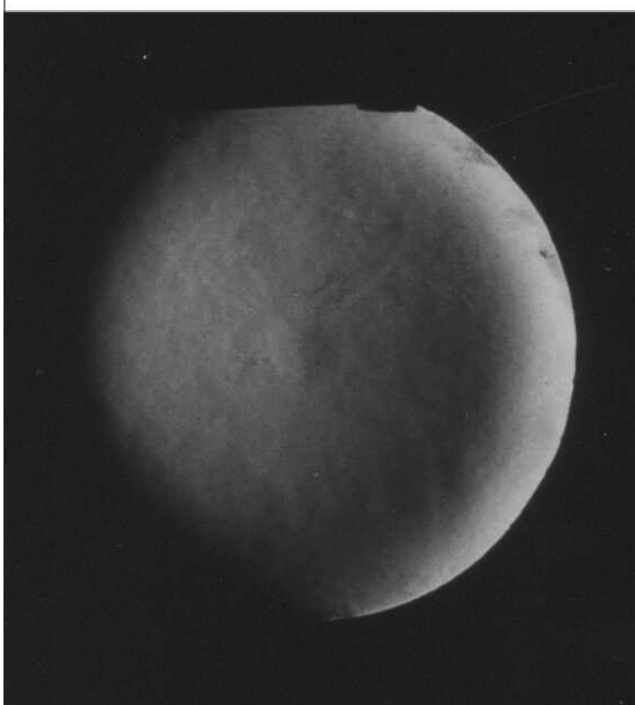


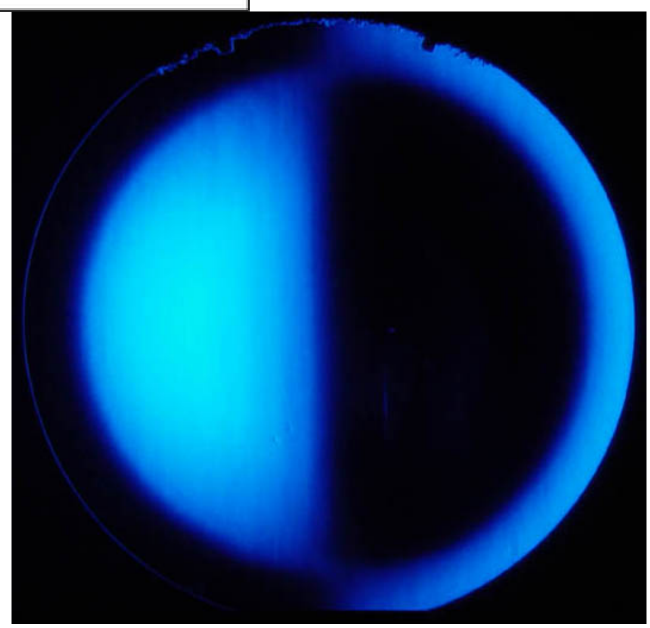
FIG. 13-14 Foucault test of spherical mirror at its center of curvature (a); test of parabolic mirror with auxiliary testing flat (b); test of mirror with symmetrical, raised, intermediate error zone (c).

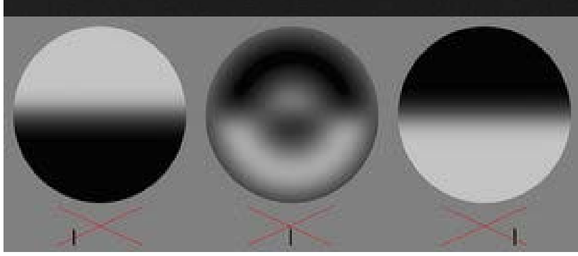
Foucault Knife Edge test

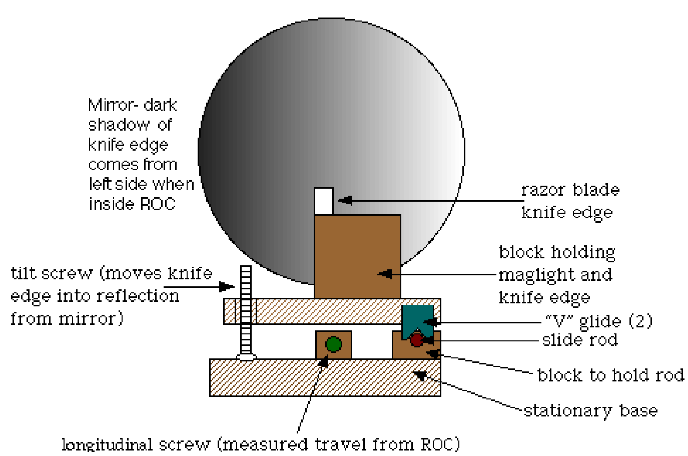
- Knife edge test shows shape of surface
- Shows up any defects – want a smooth surface
- Shape determination harder
- Need to get knife edge at focus point to get right image





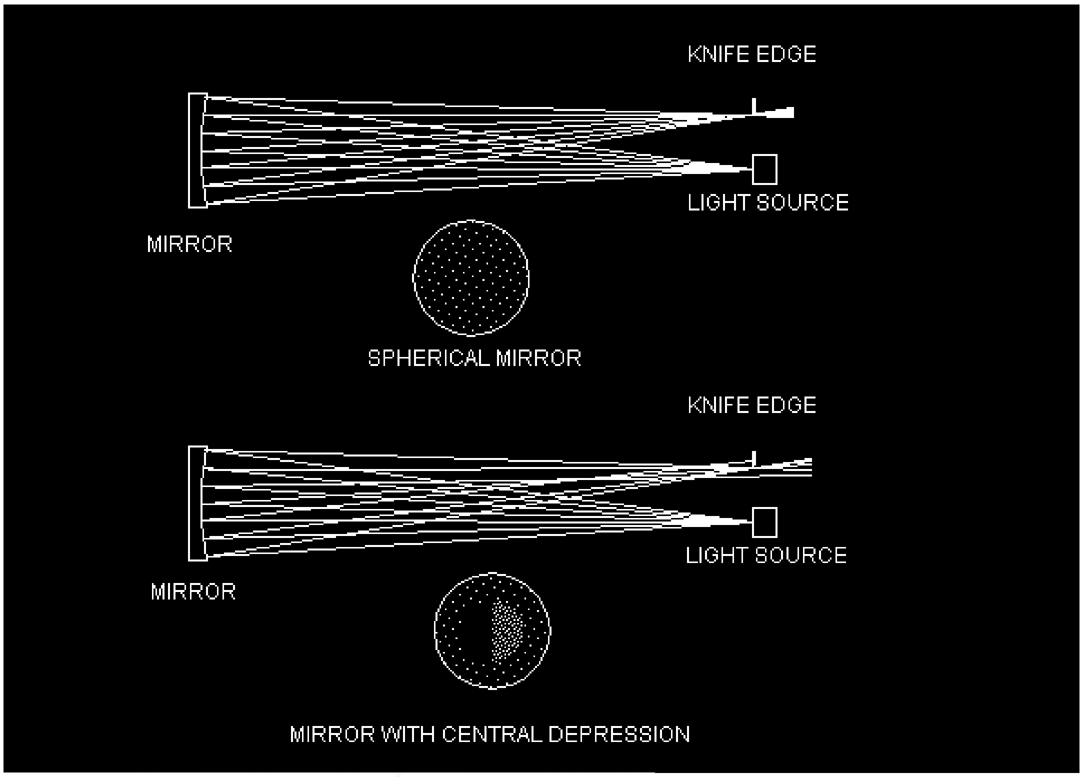


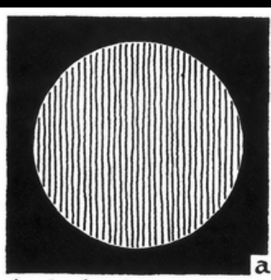




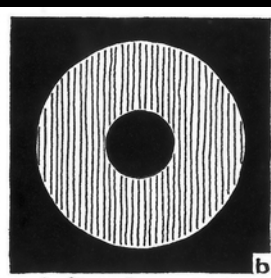
Foucault Knife Edge Shapes: Figuring

- Shape of pattern tells us about surface
- Flat surface spherical mirror
- Foucault you just seeing shape
- Parabolic want a slight doughnut shape
- Test flats against known spherical shape

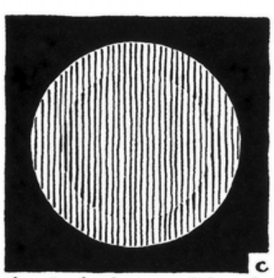




spherical mirror tested at center of curvature



parabolic mirror tested with a flat testing mirror

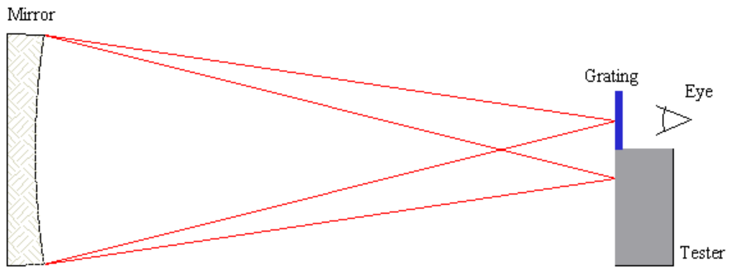


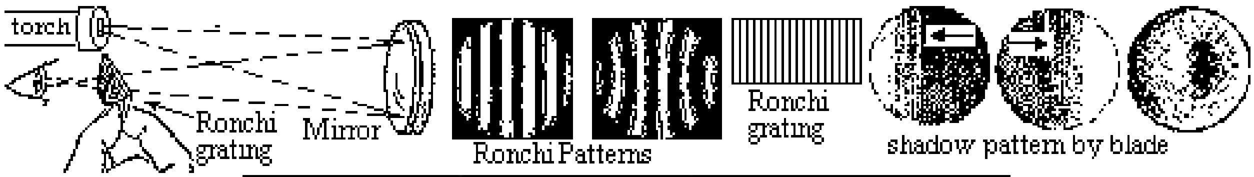
spherical mirror with raised annular ridge as tested at center of curvature

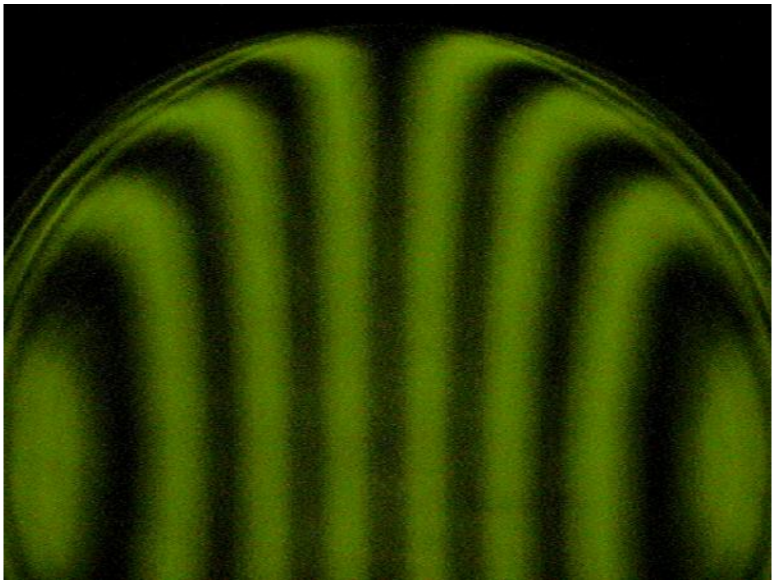
FIG. 13-15 Appearance of mirrors under the Foucault test of Fig. 13-14.

Ronchi Testing

- Ronchi test – observe mirror with a “Ronchi” grating
- Wildly spaced parallel lines
- Creates parallel lines on mirror
- Where lines bend can see defects

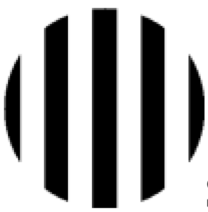


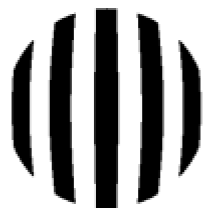


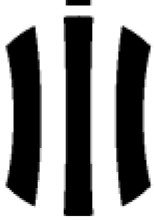


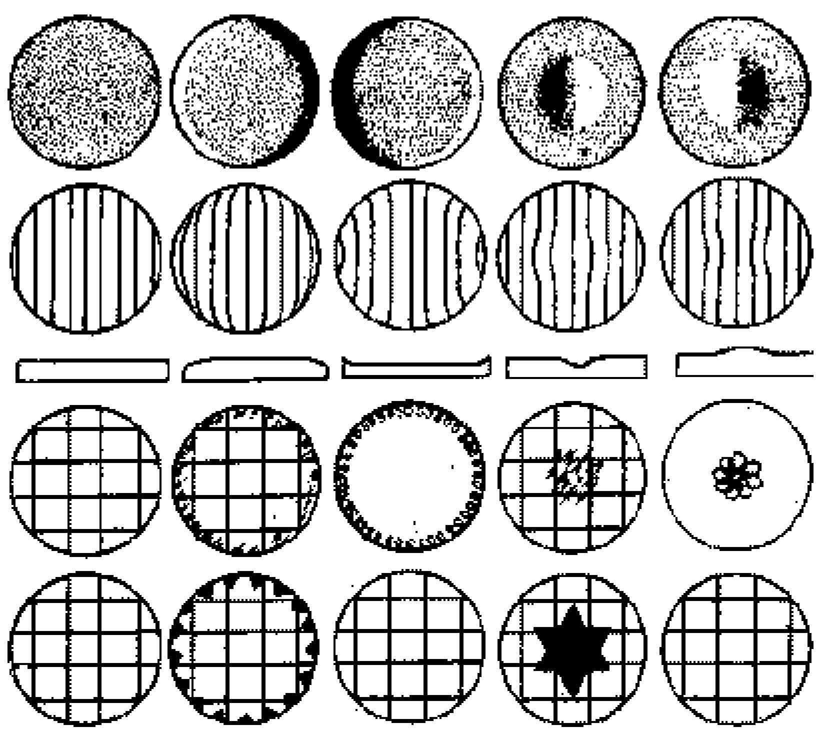
Foucault and Ronchi Testing Patterns

- Ronchi Watch the shape of the lines
- Straight lines – spherical
- Slight inward curve parabolic
- Bend outward Oblate spheroid
- Bend at edge – turned down edge
- Foucault and Ronchi show the shape of the surface
- Now use different strokes and lap shapes to correct this
- Test and reshape then test again


Spherical mirror


Parabolic


Oblate spheroid


Foucault

Ronchi

Surface

Laps to correct

Twyman-Green Interferometer

- Use Interferometer to view surface
- Add lenses to turn mirror light into parallel beam
- Easy to detect defects – problems in surface

Figure 15.6
Twyman-Green Interferometer

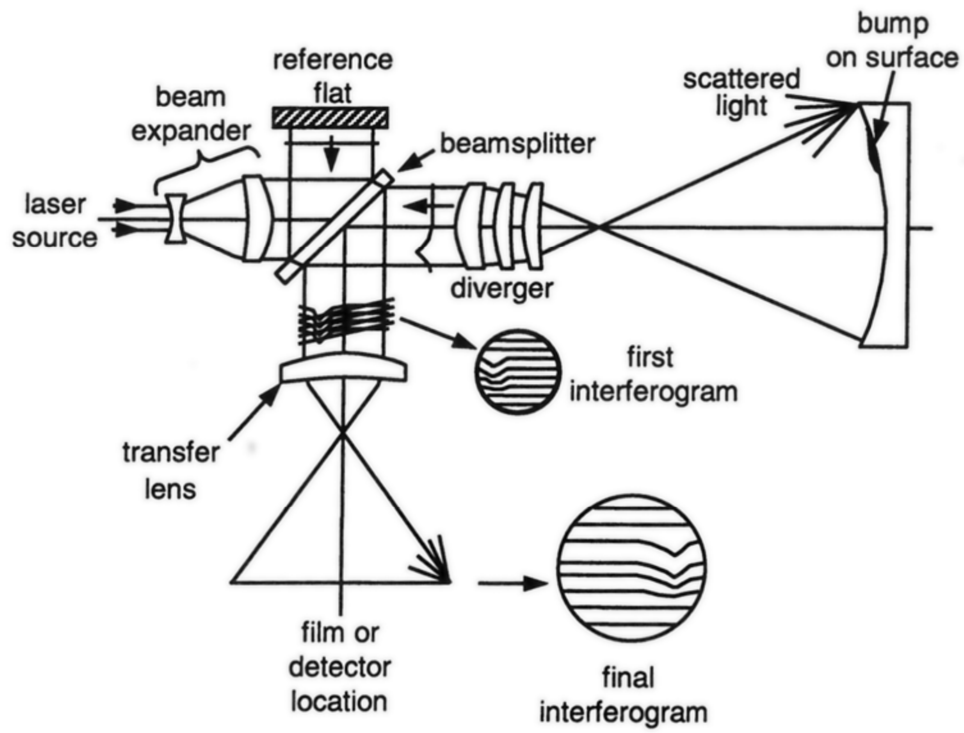
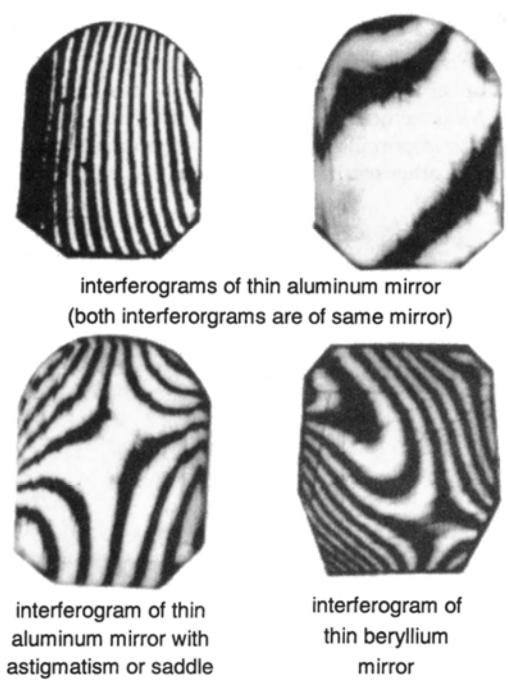
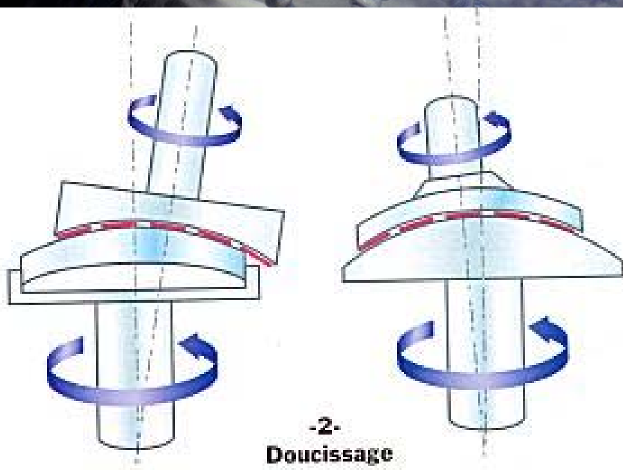


Figure 15.9
Typical Interferograms of Nominally Flat Mirrors



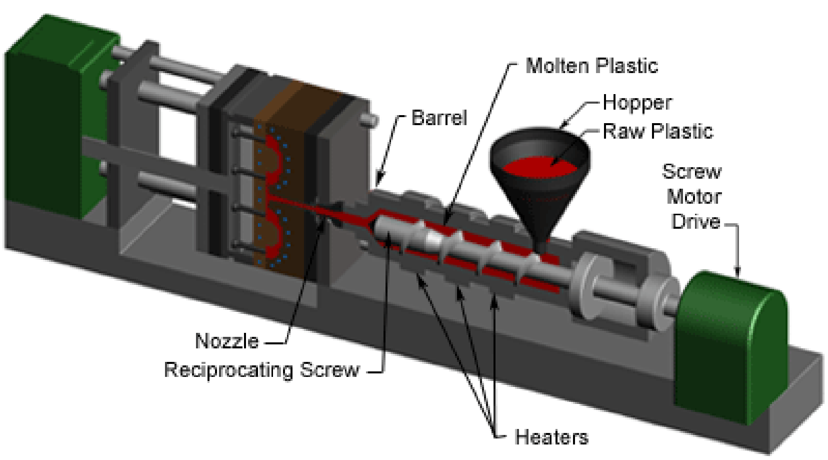
Lens Making

- Lens making same process
- But usually make many copies of same lens
- Much larger shaping of glass
- Use a grinding tool to make rough shape
- Now use shaped tool for each lens
- Finer grits and polishing done similar but with a master for lens
- Auto grinders shaper, rotate lens and tool, and polish
- Eyeglass companies use similar system



Casting Lenses

- Lens has such large change can make plastic cast lenses
- Lower quality, but much cheaper
- Used in cheap cameras, web cams, DVD players
- Use an injection moulding machine
- Start with raw plastic beads
- Grind and melt them
- Inject into mold
- Mold opens after cooling
- Can get nearly $\lambda/4$
- Create both lens and optical fixture eg for DVD lens system



Laser Confinement Fusion

- Use powerful laser to compress and heat hydrogen
- Hydrogen stored in very small pellets
- Outside of pellet boiled off by laser beam
- Ablation causes plasma
- Pellet compressed 4-5 times density of liquid hydrogen
- Reaches temperature/pressure of sun core
- Get Fusion reaction

$$H^3 + H^2 \rightarrow He^4 + n + 14MeV$$

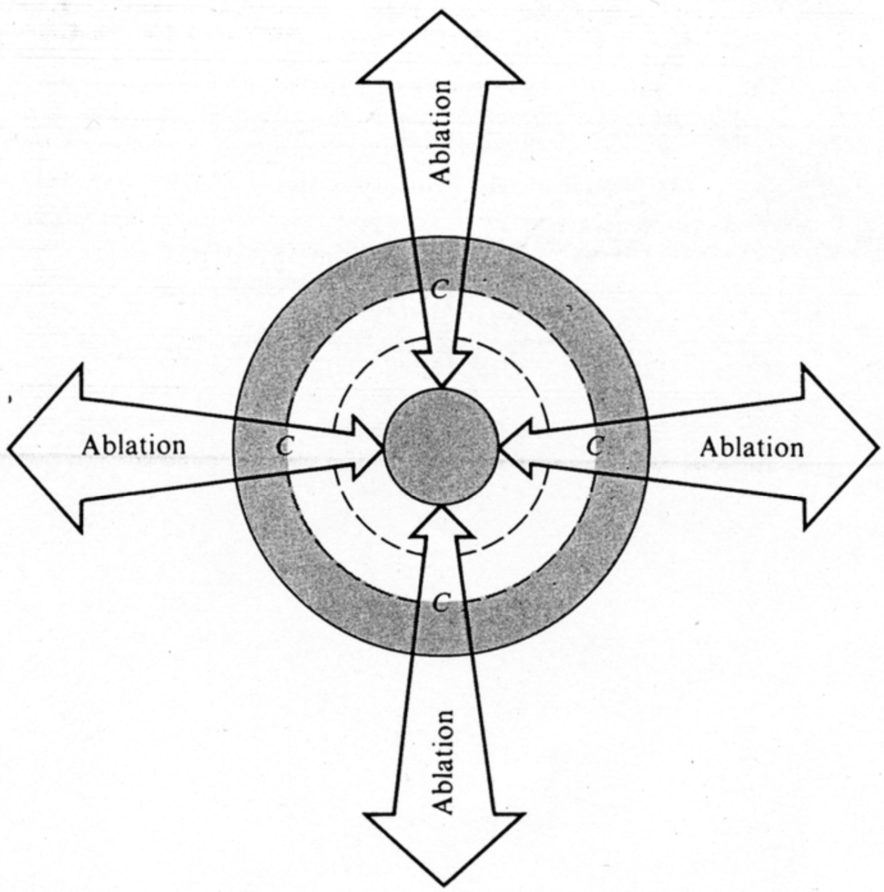


Fig. 9.10 Heating the deuterium-tritium ice pellet causes ablation of the outer surface. The reaction to this outward expansion of material is a compressional wave force (denoted as *C*) inward.

Laser Fusion Reactor

- Pellets dropped into reactor
- Laser pulse (40 nsec & terawatt) ignites compression wave
- Energy from fusion carried in neutrons & helium 3
- Liquid Lithium shield adsorbs neutrons and energy
- Regular "steam" generator to get power

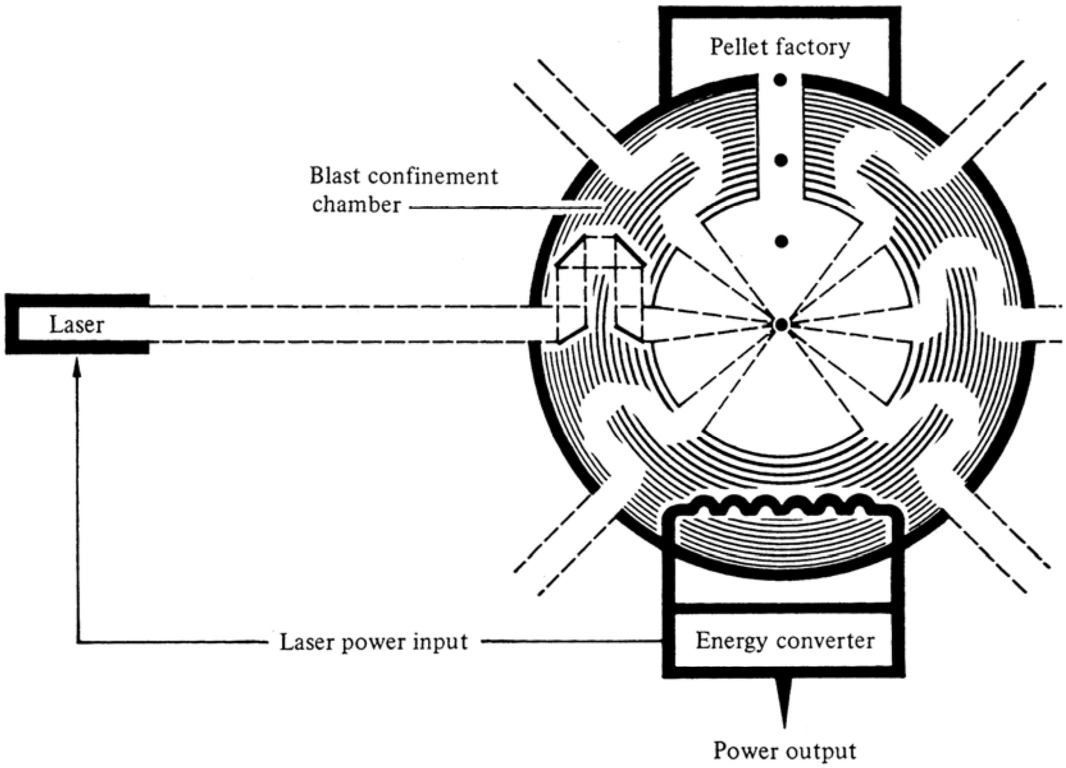
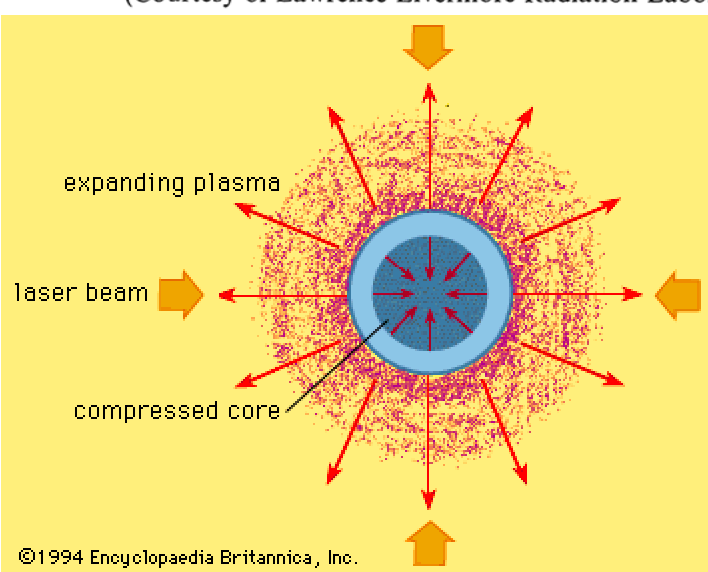
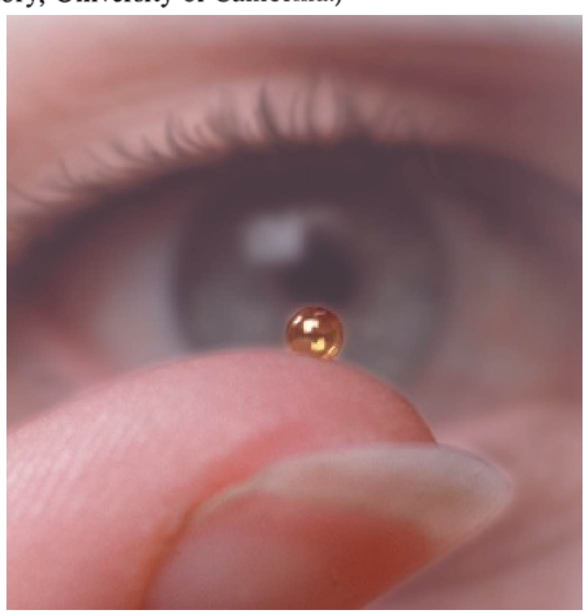


Fig. 9.13 Schematic drawing of a laser fusion power plant. The contorted beam path is designed to admit the laser beam, yet block x-ray and neutron emission from the reaction. (Courtesy of Lawrence Livermore Radiation Laboratory, University of California.)





Argus Laser Fusion Facility

- Lawrence Livermore Labs: 2 Terawatt in 1 nsec pulse
- Nd:yag/glass laser built in 1976
- Demonstrated concepts for laser confinement fusion
- Problem: need to have pellet heated very uniformly
- Thus next stage increased number of beams

Shiva Laser Fusion Facility

- 20 Beam Nd:Yag system
- Lawrence Livermore Labs: 30 Terawatt, 1 nsec
- Most important result: needed to go to shorter wavelength

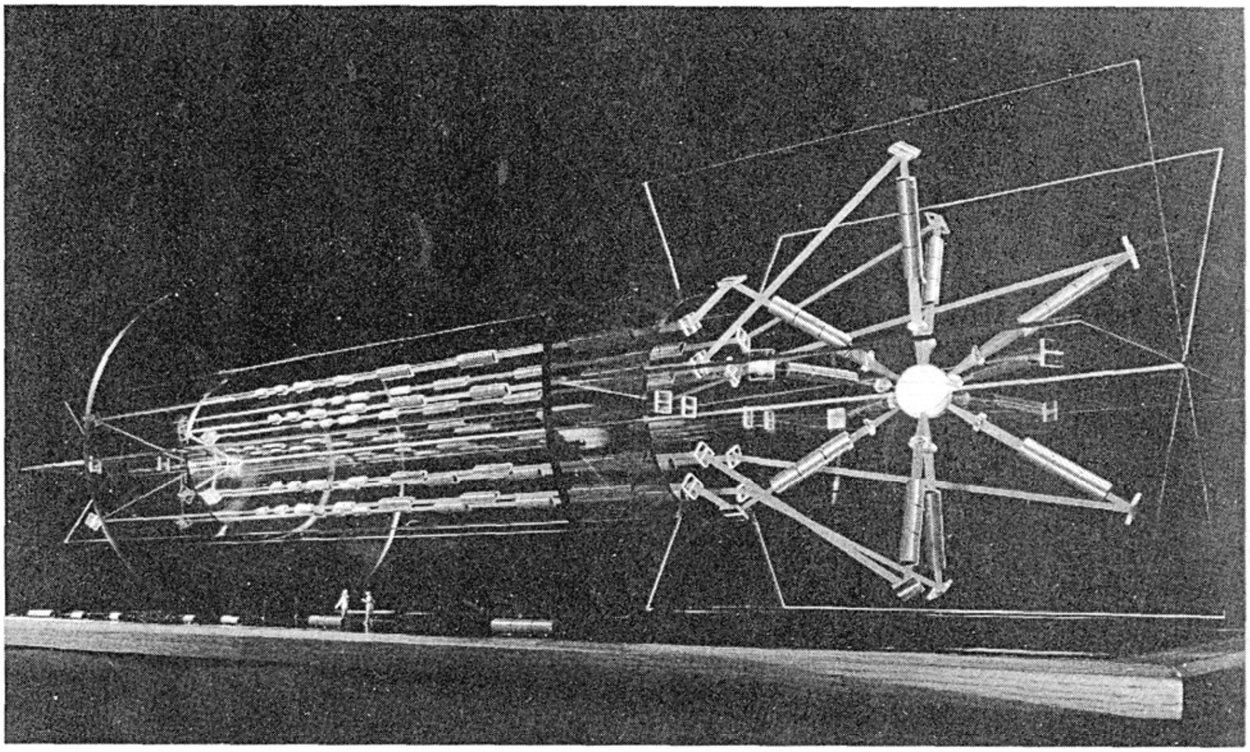
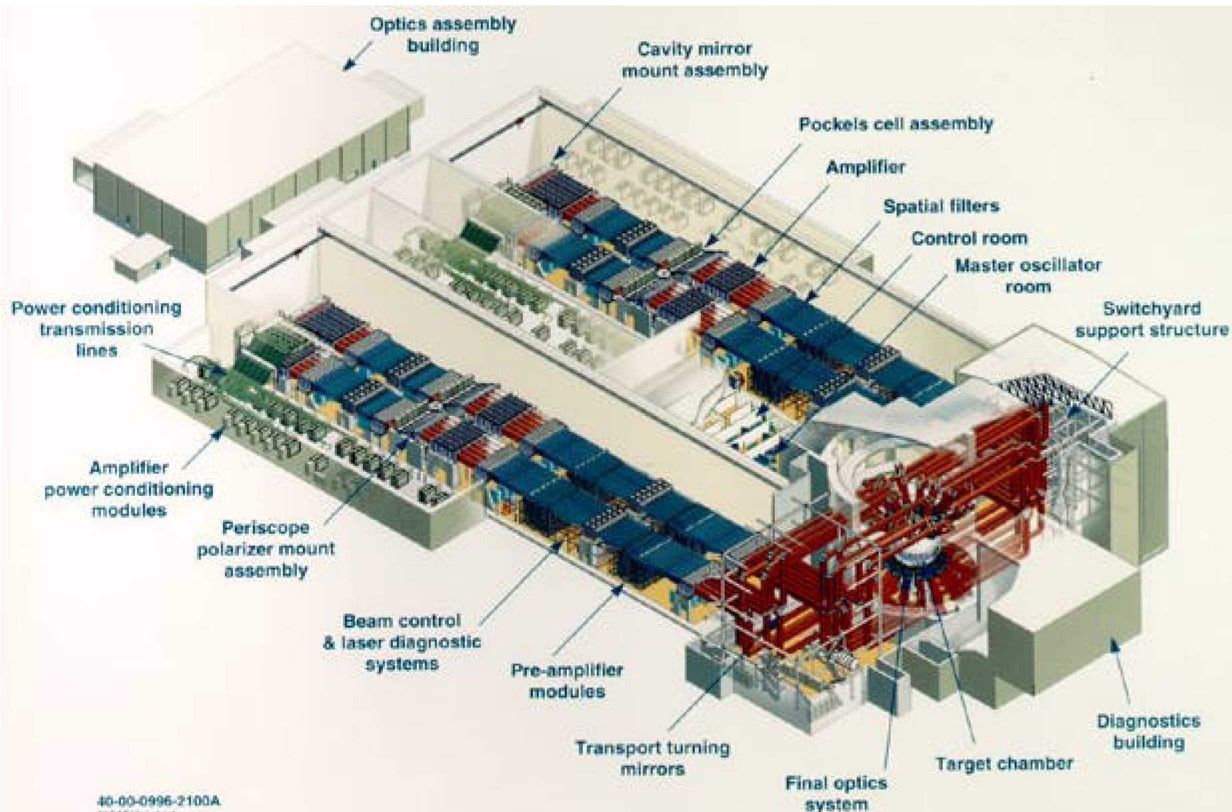
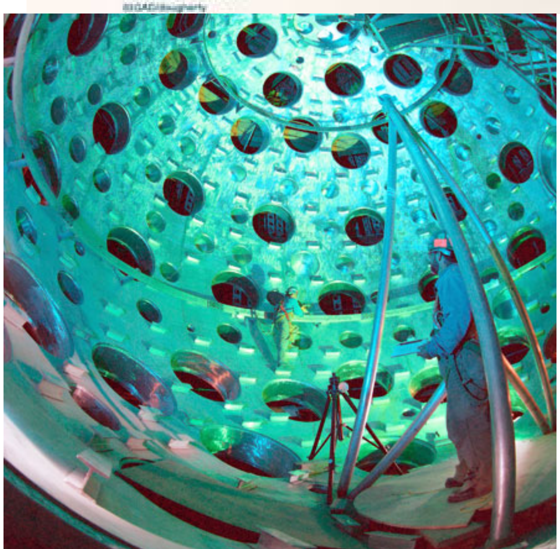


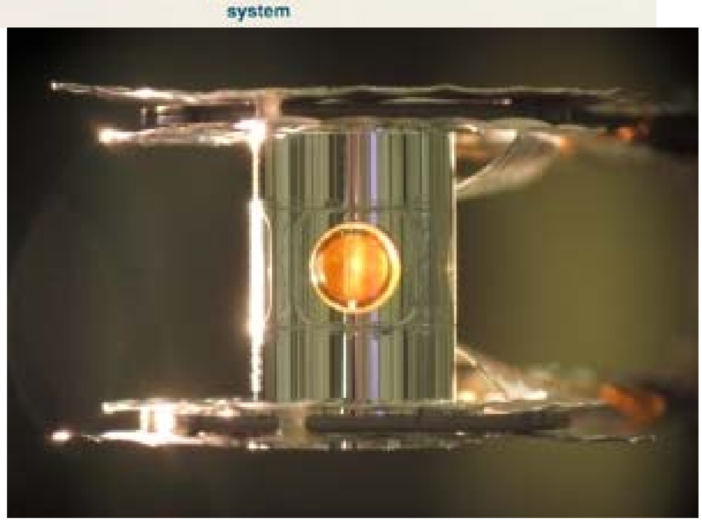
Fig. 9.12 Model of a 12-arm Shiva laser facility. The master oscillator is centrally located in the background of the figure. Each line corresponds to an Nd:glass amplifier chain. In the foreground is the combustion chamber with incoming beams arranged symmetrically about the center. The actual system contains 20 amplifier arms. (Courtesy of Lawrence Livermore Radiation Laboratory, University of California.)

National Ignition Facility

- National Ignition Facility (NIF) newest design
- 1.8 megaJoul, frequency tripled Nd:glass laser at 351 nm
- 10 ps pulse, 10^{19} W/cm^2
- 192 beam lines combined
- Test concepts with Peta Watt laser
- 1.25x10^{15}W, 0.55 ps pulse, 1021 W/cm^2
- Located at Lawrence Livermore Labs

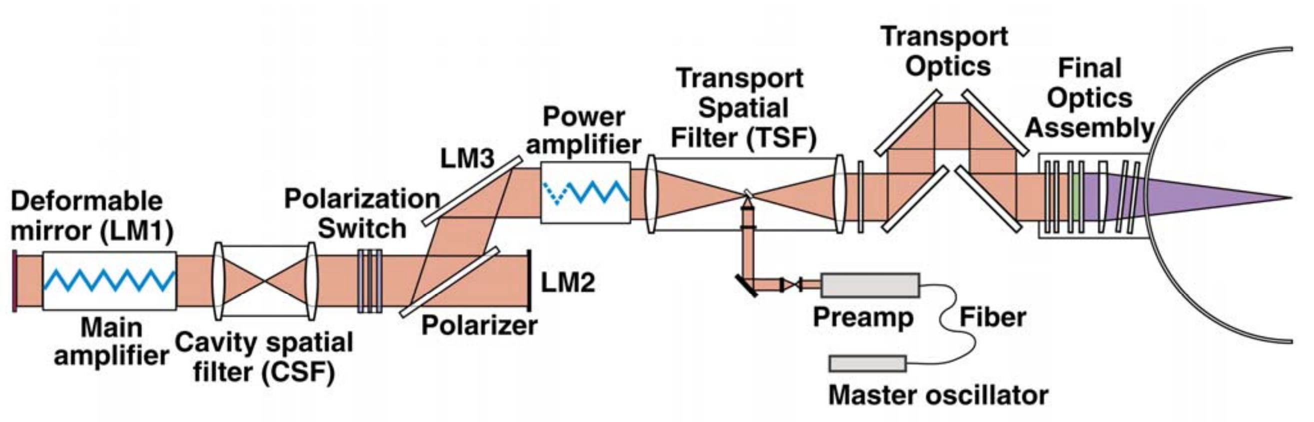






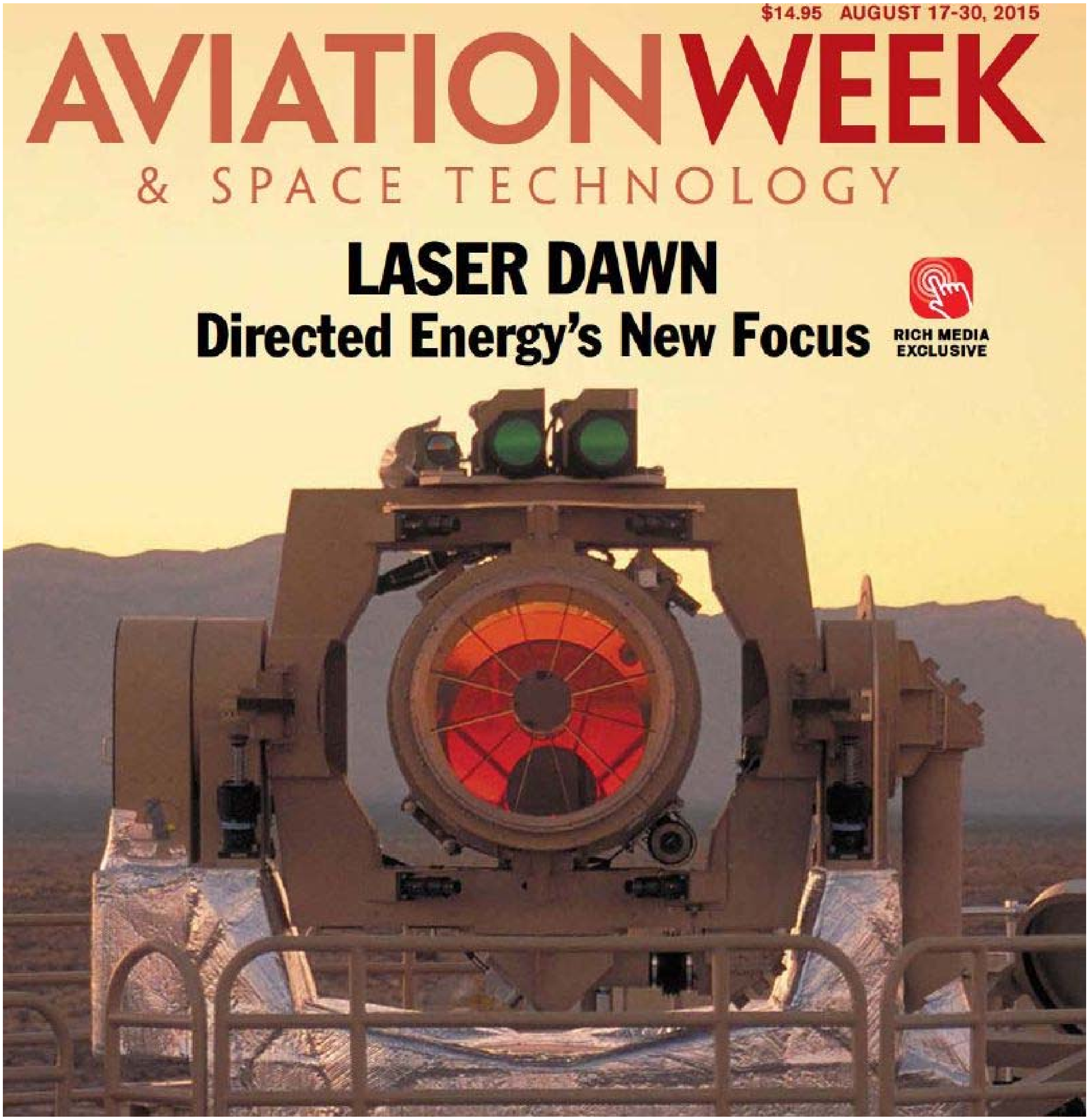
National Ignition Facility

- Beam starts with a Injection Laser System
- Master oscillator Ytterbium dopped fiber laser
- 48 beam lines with 16 laser Nd:glass amplifers
- Each beam line has 4 beamlets
- Beams converted to 3rd harmonic then focused
- 192 beam lines combined to reach target with psec of each other
- Final system 500 TerraWatts!
- Feb. 2014 NIF exceeded energy breakeven by factor of 2
- Point where Fusion energy > laser input energy
- Next full break even where Fusion energy > power to laser



Laser Weapons – the Dawn of the Death Ray

- Laser weapons before now too heavy & low efficiency
- Eg Chemical laser weapon – called Directed Energy Weapons
- New lasers (diode pumped fiber and solid state) 60-70% efficient
- DARPA 100-150 kW anti aircraft/missle laser by 2018
- 30kW prototype by General Atomics
- Weight 1.5T – ship and ground defence
- Airborne systems also planned



Laser Flight

- Use orbital laser satellites to send down beams
  orbital solar power satellites
- Light focused and tracts aircraft
- Flight takes off normally - regular engines
- Switches to laser drive for cruse section of flight
- Significant savings in fuel & no green house gases
- Works in upper atmosphere

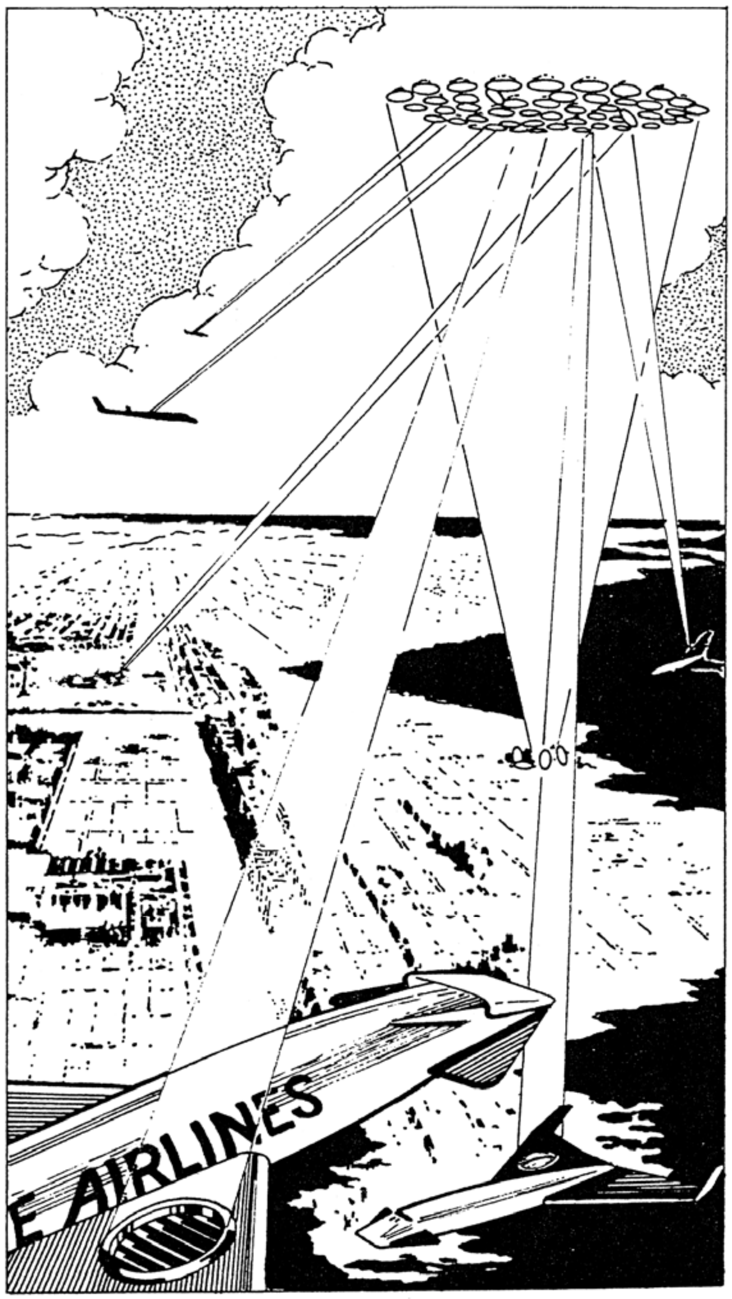


Figure 2–6. Concept for laser-powered aircraft (after Beckey & Mayer, Aerospace Corp., 1976); redrawn by artist R. Rue.

Laser Powered Turbofan

- Beam system uses feedback to keep laser on plane
- Keeps power plant on earth (or in space with orbital solar plants)
- Laser light focused into heat exchanger
- Acts as black body cavity
- Heat exchanger heats air, creating expanded volume
- Same as in regular engine but now with just heat
- Air expands as in regular turbofan
- Engine runs without fuel and pollution
- No CO2 production
- Previous interest during energy crises periods

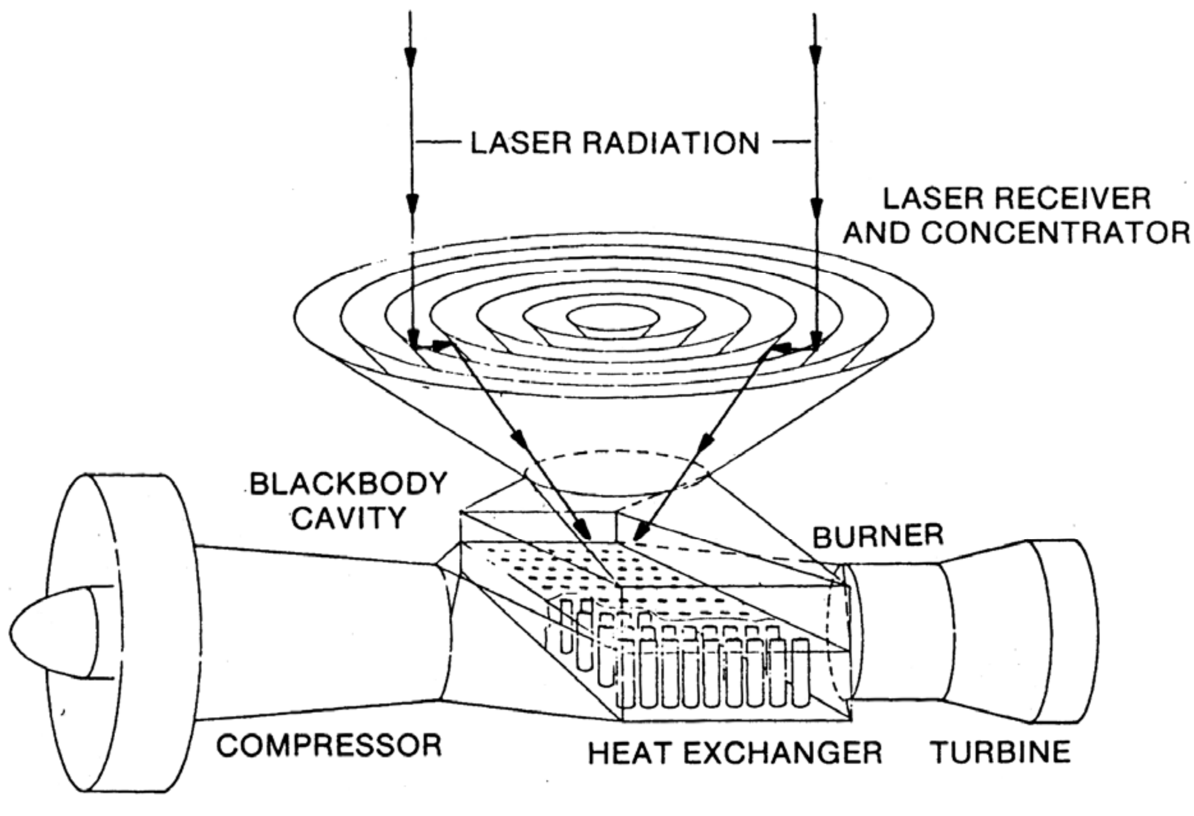
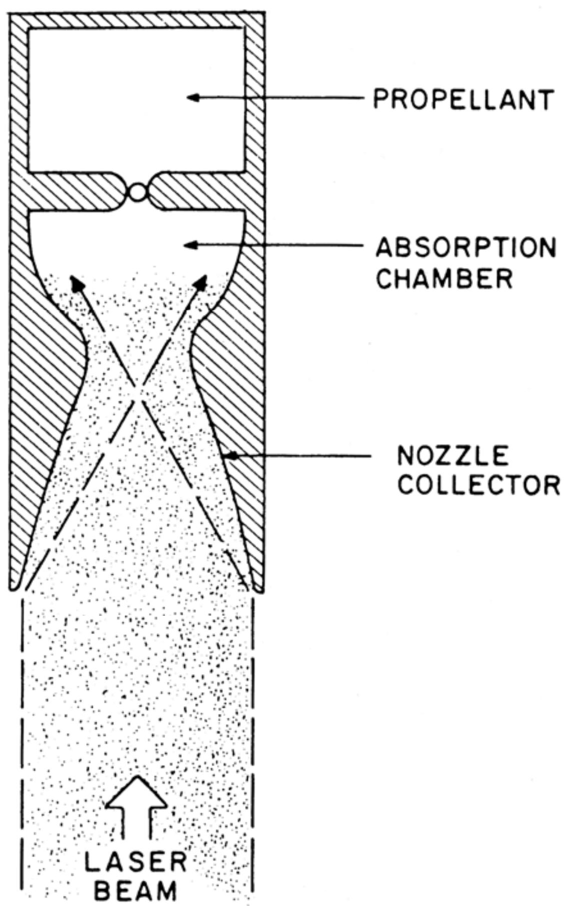
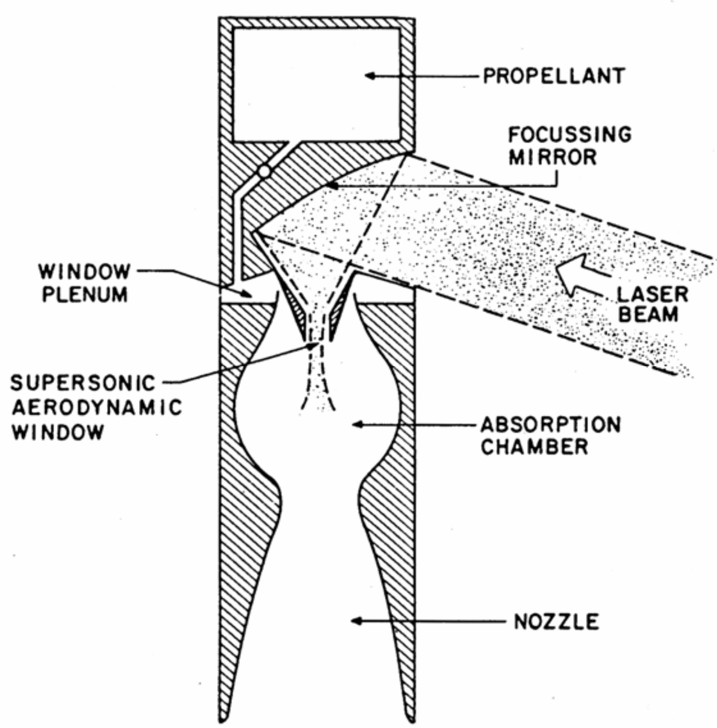


Figure 2–7. Laser-powered turbofan concept (Hertzberg and Sun, Univ. of Washington, 1978)

Laser Driven Rocket Engines

- General rocket problem: need to lift huge amounts of fuel
- Instead leave the power plant on ground: send energy by laser
- Laser light focused into rocket chamber
- Absorbed by "fuel" eg ice/water
- Fuel boils off and expands in chamber
- Can be heated much higher than regular material
- Very simple construction
- Alterative design: light enters side window
- Less problem with blocking by exhaust
- Estimate that would have Specific Impulse of 1000-2000 sec
- Specific Impulse time 1 pound of fuel produces 1 pound of thrust
- Shuttle engines I_{sp} 430 sec
- Small increase in I_{sp} gives large gain in payload





Laser Detonation Propulsion

- Also called External Radiation Heating (ERH)
- Aircraft shape forms engine
- LSD - Laser Shock wave Detonation moves along body

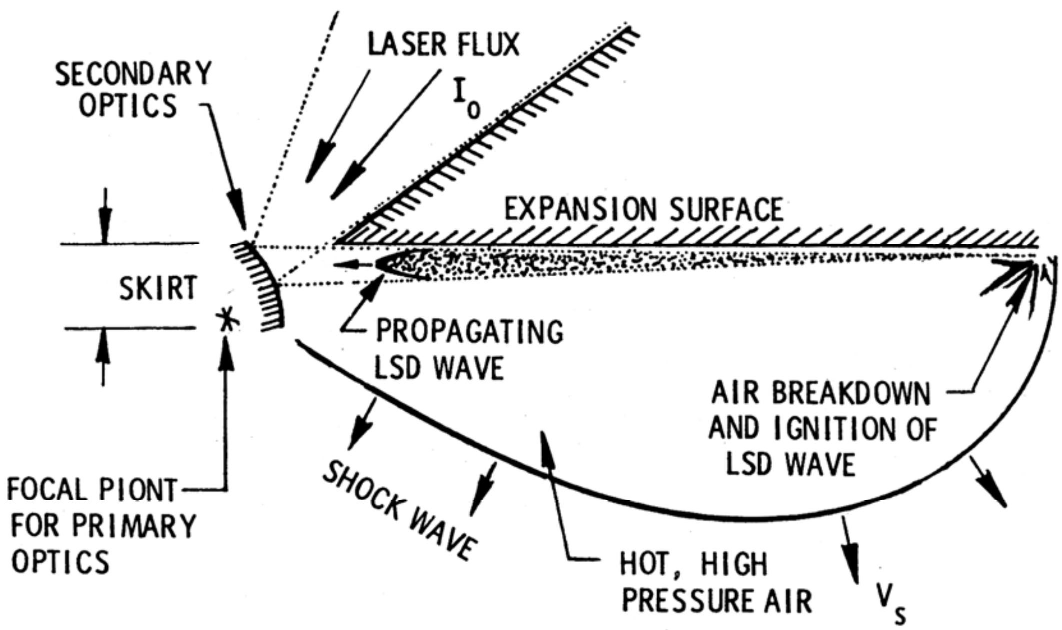


Figure 5–2. External radiation-heated (ERH) thruster concept

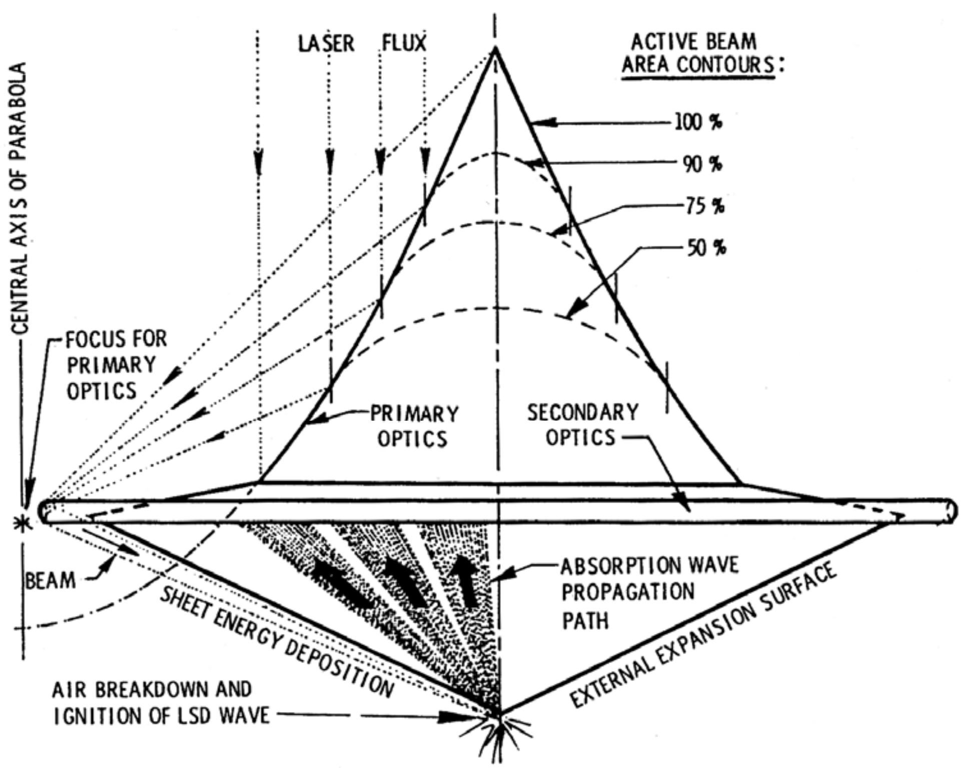


Figure 5–6. Small-wing radial IRH/ERH transport configuration in lateral translation flight (central focus)

Laser Flying Saucer

- Can shape top surface as mirror to focus laser light
- Rotate to create stability & even power
- Create Laser Detonation wave at bottom edges
- Lifts the body
- Change direction by tilting top
- Result a Flying Saucer
- Several experimental models have flown

Laser Detonation Flight

- If laser light focused to enough intensity
- Air breaks down, get a detonation
- Creates a shock wave
- Very powerful use of laser light

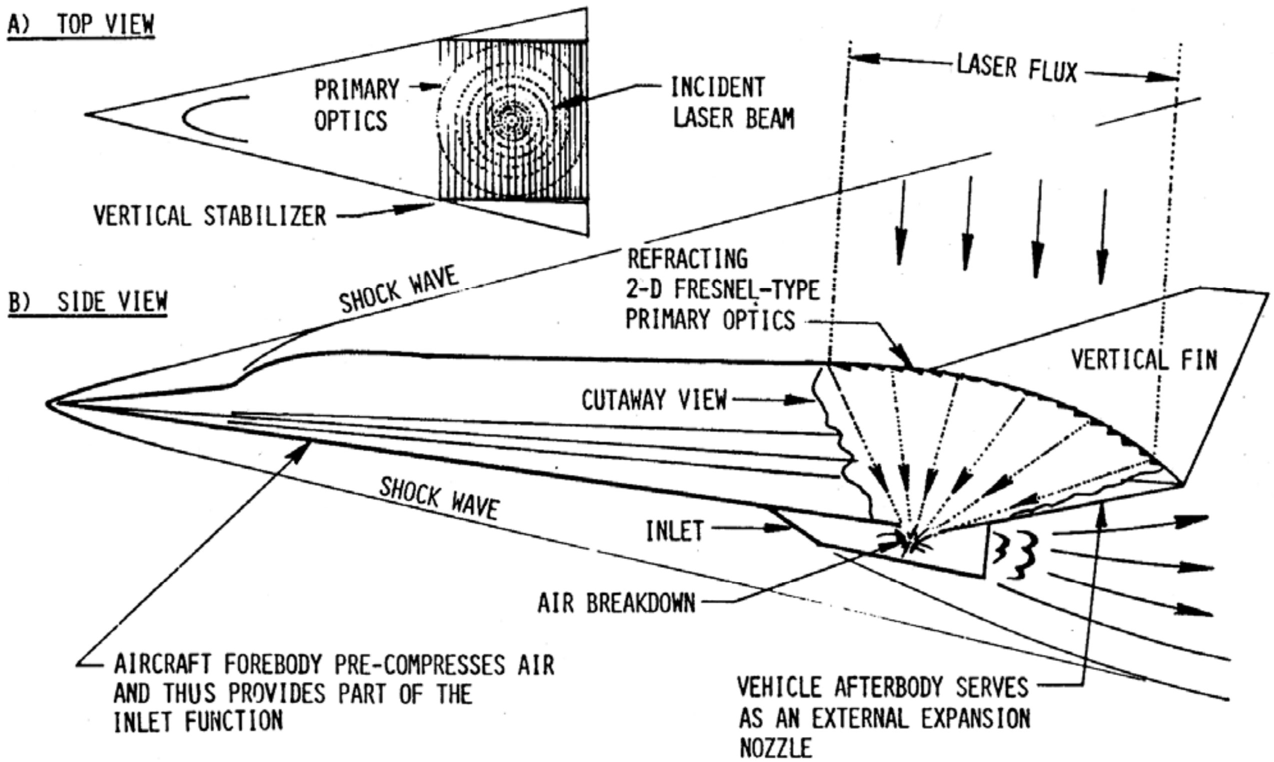


Figure 5–1. DELTA/IRH transport with transverse 2-D Fresnel lens (subsonic and VTOL capability)

Laser Driven Lightsail to Stars

- Use laser beam to drive solar sail – no reaction mass
- 47T Watt laser beam for ship mass ~10Tonnes
- 1000 km lens focuses light at reflecting sail
- At destination large sail focuses beam on smaller sail to stop

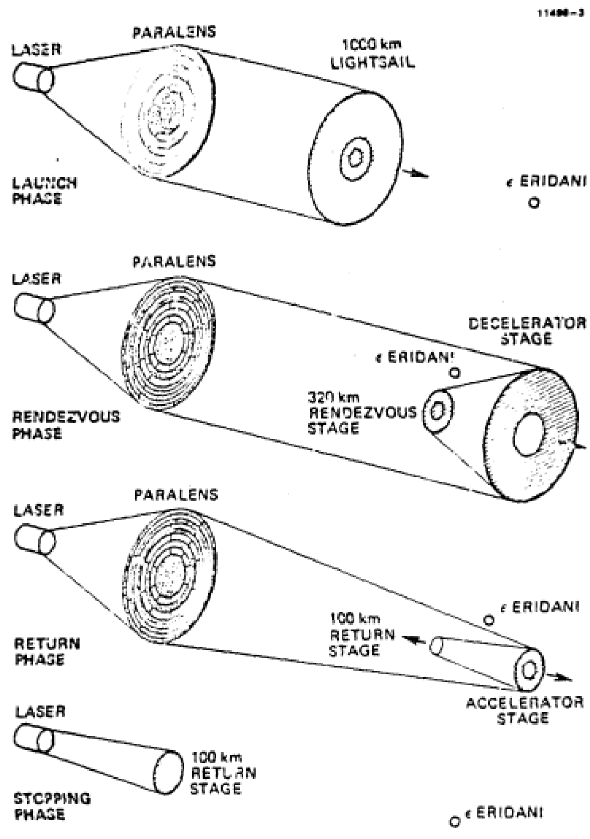
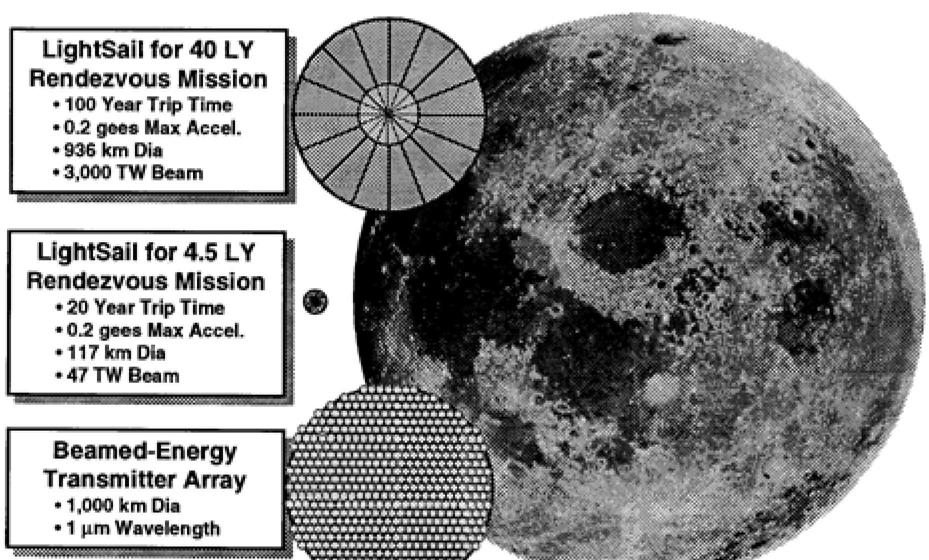


Figure A-2. Roundtrip Interstellar Travel Using Laser-Pushed Lightsails.



Courtesy: Robert Frisbee

Breakthrough Starshot

- Alternative – send very small probes
- Cargo is Starchip – 1 cm, ~ 1gm mass chip sized nanocraft
- Sail is only 5-12 m dia
- Laser driven light Sail to Proxima Centura (4.2 light years)
- Target is planet Proxima Centura b
- 1 sq Km Phased array of lasers totalling 100GW
- Accelerate at $100 Km/s^2$ until 20% light speed ($6x10^7$ m/s)
- Fleet of 1000 spacecraft