

**CLASSICAL ORBITAL ELEMENTS (COEs)
CHECKLIST**

- Size**—semi-major axis, a
- Shape**—eccentricity, e
- Orientation**
 - orbit plane in space
 - inclination, i
 - longitude of ascending node, Ω
 - orbit within plane
 - argument of perigee, ω
- Location**

True anomaly, v , tells us the *location* of the satellite in the orbit. Of all the COEs, only true anomaly will change with time (as long as our two-body assumptions hold) as the satellite moves around in its orbit.

Now that you've seen all six of the classical orbital elements, we can show four of them together in Figure 5-8 (we can show size and shape only indirectly in the way we draw the orbit). Table 5-3 summarizes all six.

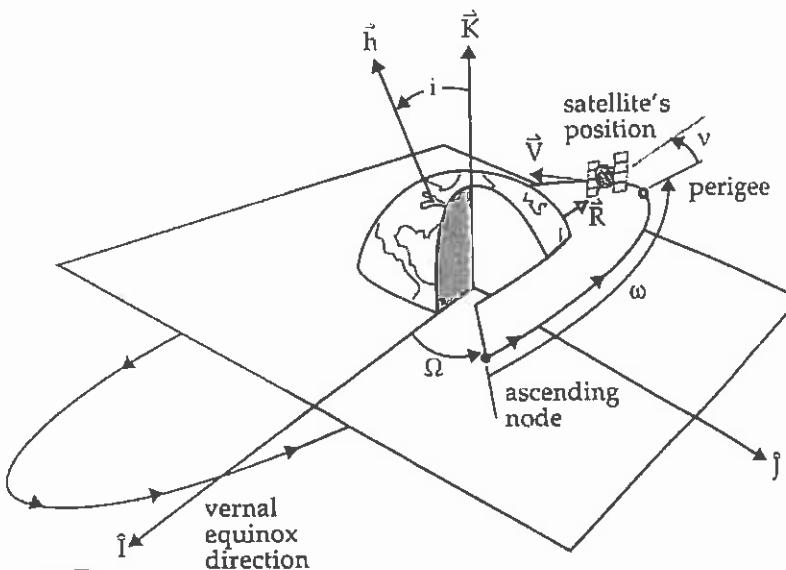


Figure 5-8. Classical Orbital Elements. Here we see four of the six COEs. We can use the COEs to find the position, R , and velocity, V , of the satellite. The other two COEs, semi-major axis, a , and eccentricity, e , specify the size and shape of the orbit.

Table 5-3. Summary of Classical Orbital Elements.

Element	Name	Description	Range of Values	Undefined
a	semi-major axis	size	Depends on conic section	never
e	eccentricity	shape	$e = 0$: circle $0 < e < 1$: ellipse	never
i	inclination	tilt, angle from \hat{K} unit vector to specific angular momentum vector \hat{h}	$0 \leq i \leq 180^\circ$	never
Ω	longitude of ascending node	swivel, angle from vernal equinox to ascending node	$0 \leq \Omega < 360^\circ$	when $i = 0$ or 180° (equatorial orbit)
ω	argument of perigee	Angle from ascending node to perigee	$0 \leq \omega < 360^\circ$	when $i = 0$ or 180° (equatorial orbit) or $e = 0$ (circular orbit)
v	true anomaly	Angle from perigee to satellite position	$0 \leq v < 360^\circ$	when $e = 0$ (circular orbit)

Den skisserer også van Allen-beltene som har stor betydning for valg av banebøyler, som blir diskutert i kapittel 4.

- GEO ligger i ekvatorialplanet med en baueradius som beregnet ovenfor.

- Polbanene har en inklinasjon på 90 eller nærmere 90 gradet. De er oftest sirkulære og med en høyde på 300 til 1500 km. En fordel med polbaner er at en enkelt satellitt med tiden kan dekke hele jordkloden. En spesiell kategori polbaner er de solsynkronne, som vil bli behandlet senere.

- HEO, baner med høy inklinasjon og ofte med stor eksentrisitet kan gi god dekning av områder med høy inklinasjon. Banene kan gjøres geosynkron (men ikke geostasjonære) for å gi faste dekningsområder. Molniya-banen tilhører denne kategorien.

- LEO, med banebøyler i området 10 000 km, og gjerne med høy inklinasjon kan gi god dekning av hele kloden. Noen av de nye satellittsystemene for multimedia og mobilkommunikasjon er basert på satellitt-konstellasjonen med slike baner.

- LEO, har banebøyler begrenset nedad av friksjon i atmosfæren og oppad av van Allen beltet. Mange vitenskapelige satellitter og satellitter for jordobservasjonsformål har benyttet slike baner. Andre kjente brukere er de nye systemene for mobilkommunikasjon, Indium med 66 satellitter, og multimedia-systemer, som Bill Gates' Teledesic som opprinnelig hadde 840 satellitter.

2.9 Den geostasjonære bane:

Den geostasjonære banen har noen fordelaktige egenskaper:

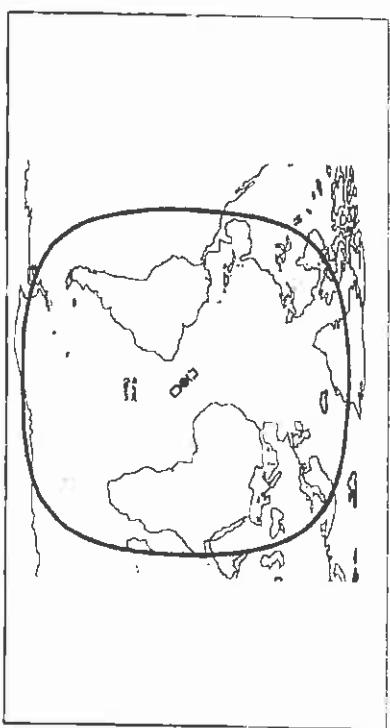


Fig. 2.17: Dekningsområdet for geostasjonær satellitt på 30 grader vest.

Oppgave 1a
Oppgave 1b

- Den dekker en stor del av jordkloden, som vist på figur 2.17.
- Satellitter i GEO står fast i forhold til enhver punkt på jordoverflaten.
- Det er mulig med en enkelt satellitt å bygge et system som gir tidskontinuerlig dekning av et område på Jord.

Utenper er at

- Avstanden til satellitten er stor.
- Polaroidene dekkes ikke.
- Det er trensel i banen.

Den geostasjonære banen er en viktig, begrenset ressurs som det kjempes om. Det er ikke tale om fysisk trensel; satellittene styres i dag meget nøyaktig i sine baner. Ved 19,2 grader opererer 5 ASTRA-satellitter i nominelt samme baneposisjon ved at de beveger seg i en fast formasjon. Det er mer tale om vinkelavstand. Utviklingen går i retning av stadig mindre jordskasjoner. Disse har nødvendigvis bredere antenneløber, og derved begrenset oppslasningen i vinkel. Det brukbare frekvensområdet er begrenset, og da vil det nødvendigvis bli kamp om overføringskapasiteten.

ITU, den internasjonale teleunionen, forsøkte i 1979 å løse problemene med tildeiling av baneposisjon for TV-satellittene ved som hovedregel å gi hvert land en bestemt baneposisjon. At dette forsøket feilet skyldes bl.a. at interessen for nasjonal deling var minimal, og at regionale systemer med et stort antall TV-programmer fra ett banepunkt viste seg å være mer attraktivt. Eksempel er Telenors satsering på "1 grad vest", EUTELSATs Hotbird-posisjon ved 13 grader øst, og ASTRA-satellittene ved 19,2 grader øst.

Et annet forhold som gjør utnyttelse av banen vanskeligere er at visse områder er spesielt attraktive. I området fra 70 til 75 grader øst vil GEO satellitter være synlig over hele området fra Japan til Vest-Europa.

Jordkloden, sett fra en geostasjonær satellitt INTELSAT 707 på 1 grad vest, er vist på figur 2.18.

<http://www.outrunlab.ch/cgi-bin/uncgi/Earth>

2.9.1 Baneperturbasjoner.

En satellitt i den geostasjonære banen vil bli utsatt for krefter som forandrer baneparametrerne. Vi kan skjelne mellom to hovedtyper, øst-vest-drift og nord-syd-drift. For god unntak av den geostasjonære banen må satellittene holdes på plass inne snøvere grenser. Kravet er nå en "boks" på 0.1×0.1 grader, men de fleste holdes innenfor 0.05×0.05 grader.

Øst-vest drift skyldes inhomogeniteter i massefordelingen i jordkloden. Vi kan se det slik at tangensielle komponenter gir en øst-vest forflytning av satellittene. Dette er vist på figur 2.19. Ser for India og i det østre

dag, men på grunn av hastigheten vil den passere punktet. Resultatet blir en pendelbevegelse med en periode på nester tre år.

Nord-sør driften skyldes hovedsakelig usymmetrisk påvirkning fra sol og måne, og den kan uttrykkes som en inklinasjonsdrift. Dagens geostasjonære satellitter har drivstoff om bord til motvirking av inklinasjonsdriften, som kan være bortimot 1 grad per år, og en stor del av denne masse som må plasseres i bane utgjøres av dette drivstoffet. Det vil i mange tilfeller være begrensende for satellitteveitiden. I de tidligste tiden hadde de geostasjonære satellittene ikke drivstoff for inklinasjonskontroll. De ble plassert i bane med 3 grader inklinasjon. I løpet av en levetid på 6 år forandret inklinasjonen seg gjennom 0 til 3 grader andre veien, slik at maksimal inklinasjon var 3 grader. 1



Fig. 2.18: Jordkloden sett fra INTELSAT 707 på 1 grad vest

Stillehav er det stabile posisjonen. Satellitter som plasseres i disse punktene vil ligge i ro. I Atlanterhavet øg nord for New-Zealand er det et labilt punkt. En satellitt ved 19,2 grader vil trekkes østover, og det er nødvendig med jevne mellomrom å gi den styrkeimpulser vestover.

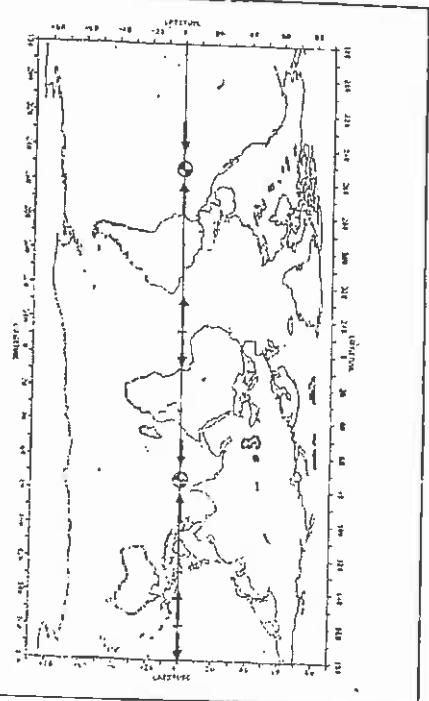


Fig. 2.19: Øst - vestdrift.

Hvis satellitten "slippes los" i en avstand på 60 grader fra det stabile punktet vil den nå det stabile punktet med en hastighet på ca 0,4 grader per

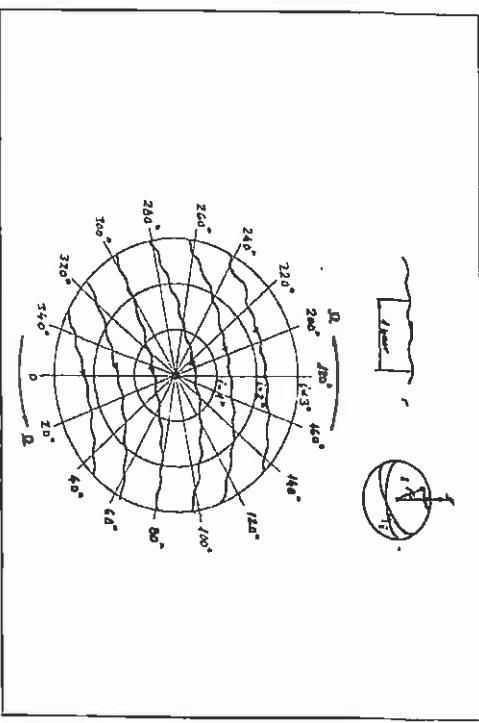


Fig. 2.20: Inklinasjonsforandring som funksjon av startverdi for Ω .

Inklinasjonen resulterer i en tilsynelatende bevegelse av satellitten over døgnet, og den beskrives et 8-tall som figur 2.21 viser. Høyden er proporsjonal inklinasjonen, mens bredden er proporsjonal kvadratet av inklinasjonen. Bredden på 8-tallet kan forklares på følgende måte: Satellitten beveger seg i en sirkuler bane med inklinasjon.

Hastigheten langs banen er konstant. Det betyr at øst-komponenten varierer over omløpsiden. Den er høyest når satellitten er lengst nord eller sørfordi banen der ligger i øst-vest retning, og den er lavest ved ekvatorpassering. I middel er den lik omdreningshastigheten for jorda, som dreier med konstant hastighet. Derfor vil den i en periode "jede" og i en annen periode "ligge bakh"

Figur 2.23 viser banesporer for en satellitt i polbane i løpet av et døgn. Om satellitten i denne perioden skal dekke alle punkt på jordoverflaten avhenger av banbøyden.

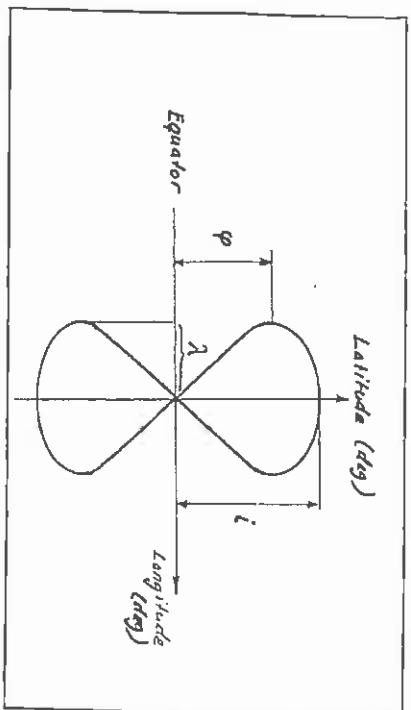


Fig. 2.21: Tilsynelatende bevegelse for nær stasjonær satellitt.

Variasjonen av inklinasjonen er bestemt av rektasensjonen for oppstigende knute, Ω , som vis på figur 2.20 viser. Skulle man benytte metoden med inklinasjonsdrift gjennom 0 måtte Ω i begynnelsen være i området 270 grader.

2.10 Polbaner

En av de viktigste fordelene med polbane, figur 2.22, er at én enkelt satellitt kan gjøres tilgjengelig eller synlig for alle deler av jordkloden. Med inklinasjon væsentlig under 90 grader vil det området som ser satellitten være begrenset til en vinkelavstand fra ekvator lik inklinasjonen, pluss den avstanden som er bestemt av banbøyden.

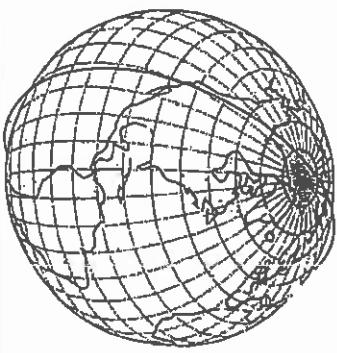


Fig. 2.22: Lav Jordbane, LEO (Low Earth Orbit).

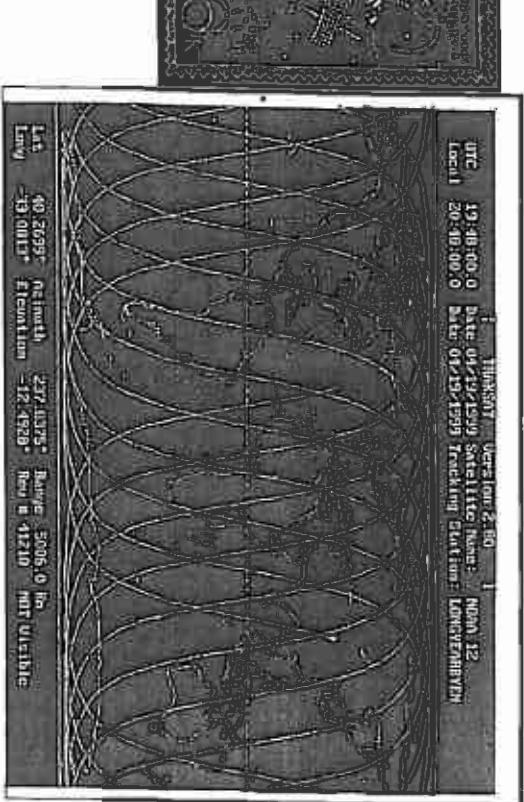


Fig. 2.23: Banespor for lavbane-satellitt i polbane.

Satellitter i tilnærmet polbane blir påvirket av avvik fra kuleform for jordkloden. Flattykking ved polene forårsaker en deining av satellitbanen som fører til en variasjon av Ω som er gitt av

$$\frac{d\Omega}{dt} = \frac{-10}{\left(\frac{a}{R}\right)^{\frac{3}{2}} \cdot (1-e^2)^2} \cdot \cos i \text{ grader/dag} \quad (2.61)$$

Før inklinasjon mindre enn 90 grader avtar Ω (oppstigende knut) vestover), mens den vokser for inklinasjon over 90 grader. Virkningen er størst for satellitter i lave baner.

2.10.1 Solsynkron baner

Ved visse kombinasjoner av baneradius og inklinasjon vil Ω øke 360 grader per år, eller ca 1 grad per dag. Da vil satellitbanen (baneplanet) alltid stå i et fast forhold til sola.

En solsynkronbane vil ligge over samme sted på jordkloden til samme lokale tid året igjenom. Det er da for eksempel mulig å få en satellitt til å bevege seg i lav jordbane uten at den kommer i jordskyggen. Dette er en morgen-kveldbane.

Oppgave 2a

Stikkordmessig løsningsforslag:

- a Avstandsmåling fra tre satellitter, en fjerde satellitt gir et overbestemt system med mulighet for korreksjon av klokken i den lokale mottakeren, som er masseprodusert og billig. Differensiell GPS er basert på posisjonsmåling i et sted med kjent posisjon. Da kan feilen registreres og den kan kommuniseres til andre brukere slik at felles feilkilder (satellitt posisjon, satellitt klokke, ionosfærisk og troposfærisk forsinkelse, etc) elimineres.

The station broadcasts a *carrier signal* at a specified frequency, regulated and licensed by the Federal Communications Commission (FCC) in the U.S. The transmitter then super-imposes the message being sent—music, news, or mission data—on top of the carrier signal, using some type of modulation scheme. The schemes we're most familiar with are amplitude or frequency modulation (AM and FM, see Figure 13-9). Spacecraft applications use other schemes as well. This signal travels outward from the station's antenna and hits your radio antenna. There, some charges accelerate. Your receiver detects this charge movement in the antenna and re-translates it to the original signal. The receiver demodulates the AM or FM signal to separate the message from the carrier signal and, suddenly, you're listening to tunes while cruising down the road.

Now we want to look at more details of communication systems to understand some of the basic principles and limitations. Let's use a light bulb to demonstrate some of these key principles. Similar to a radio transmitter, a light bulb emits EM radiation, but at a different frequency—visible light. If we put a light bulb in the center of a room, as shown in Figure 15-14, light radiates outward in all directions (assuming it's a perfect bulb with no light blockage). The intensity or brightness of the light at some distance from the bulb is called the *power-flux density*, F . Of course, the farther we get from the light bulb, the dimmer it appears. In other words, the power-flux density, which we perceive as brightness, decreases as we move farther away. From test measurements, we know the brightness actually decreases with the square of the distance, because all the output is distributed over the surface of a sphere surrounding the source. We express this as

$$F = \frac{\text{Power}}{\text{Surface area of a sphere}} = \frac{P}{4\pi R^2} \quad (15-1)$$

where

F = power-flux density (W/m^2)

P = power rating of the light bulb (W)

R = distance from the bulb (m)

We know that visible light, like that of a light bulb, is simply electromagnetic radiation. Radiation, moving equally in all directions, similar to our light bulb example from Figure 15-14, is called *omnidirectional* or *isotropic*. Now, what if we wanted to increase the brightness or power-flux density in only one direction using the same bulb? As Figure 15-15 shows, that's just what a flashlight does. This time we're still using our ideal light bulb, but we've put a parabolic-shaped mirror on one side of it. Thus, most of the light in one direction reflects off the mirror and heads in the opposite direction, and we have a directed beam of light—a spotlight—rather than an omnidirectional source. Doing this, we effectively concentrated most of the light energy into a smaller area. As a result, we get a tightness in that one direction that is much, much greater than it was

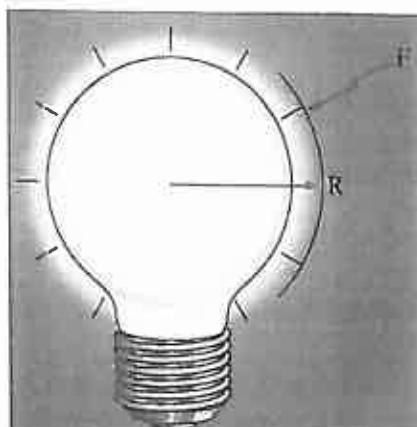


Figure 15-14. Power-flux Density. An ideal light bulb radiates equally in all directions. The brightness, or power-flux density, F , at any given distance, R , depends on the bulb's output, P .

when the bulb emitted light isotropically. We've "gained" extra power density by using the parabolic mirror.

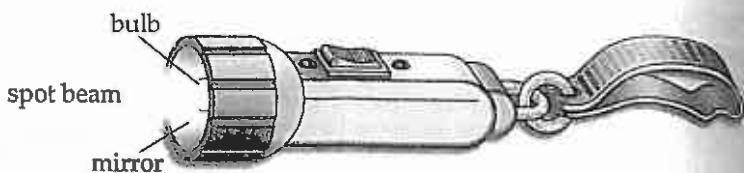


Figure 15-15. Directed Output from a Light Bulb. A parabolic mirror can direct the bulb output to give us an effective spot light. The mirror allows us to focus the bulb's energy in one direction, thus increasing the gain.

The flashlight example illustrates the basic principle of an antenna. Instead of broadcasting in all directions, wasting all that energy, specially designed "dish" antennas allow us to focus the energy on a particular point of interest, such as a receiving antenna. Spacecraft often rely on directional antennas that point toward the receiver at the ground station, making more efficient use of their transmitter's power. Ground stations usually employ another directional (dish) antenna to better receive the signal, as well as transmit commands back to the spacecraft. Similar to our flashlight's mirror, these dish antennas are parabolic-shaped to transmit and receive the radio energy efficiently.

An important antenna parameter is its gain. The gain of an antenna is the ratio of the energy it transmits in its primary direction to the energy that would be available from an omnidirectional source. In other words, the gain for an omnidirectional antenna is 1, whereas the gain for a directed antenna is greater than 1. The general expression for gain is

$$G = \frac{\text{Energy on target with a directed antenna}}{\text{Energy on target with an omnidirectional antenna}}$$

We can relate these two values for energy to an antenna's area, its efficiency, and the wavelength of the energy it's transmitting by

$$G = \frac{4\pi A\eta}{\lambda^2} = \frac{4\pi A_e}{\lambda^2} \quad (15-2)$$

where

G = gain (unitless)

A = physical area of the antenna (m^2)

η = antenna's efficiency (0.55–0.75 for parabolic antennas)

A_e = antenna's effective area ($= A\eta, \text{ m}^2$)

λ = signal's wavelength (m)

This relationship tells us that if we want to increase the gain of an antenna (and transmit our message more efficiently), we can either increase its effective area or decrease our signal's wavelength. We use the same expression for the gain of transmitting and receiving antennas.

If we multiply the transmitter's power output by its antenna gain, we get an expression that represents the amount of power an isotropic transmitter would have to emit to get the same amount of power on a target. We call this the *effective isotropic radiated power (EIRP)*.

$$\text{EIRP} = P_t G_t \quad (15-3)$$

where

EIRP = effective isotropic radiated power (W)

P_t = transmitter's power output (W)

G_t = transmitter's antenna gain (unitless)

How much of the transmitter's power does the receiver collect? Think about collecting rainfall in a bucket. The amount of rain water collected depends on how hard it's raining—the rain's density—and the bucket's size or cross-sectional area. Similarly, the signal strength at a receiver is a function of the power-flux density at the receiver and the area of the receiver's antenna. The resulting expression for the signal gathered by the receiving antenna is then

$$S = \left(\frac{P_t G_t}{4\pi R^2} \right) A_{e_{\text{receiver}}} \quad (15-4)$$

where

S = received signal strength (W)

R = range to receiver. Worst case is $R_{\max} = \sqrt{(R_{\oplus} + h)^2 - R_{\oplus}^2}$ (m), where R_{\oplus} is Earth's sea level radius, and h is the spacecraft's height above sea level (m)

$\left(\frac{P_t G_t}{4\pi R^2} \right)$ = transmitter's effective power spread over a sphere of radius, R (W/m^2)

$A_{e_{\text{receiver}}}$ = receiving antenna's effective area (m^2)

Solving the right-hand expression in Equation (15-2) for $A_{e_{\text{receiver}}}$ and substituting into Equation (15-4) results in

$$S = P_t G_t \left(\frac{\lambda}{4\pi R} \right)^2 G_r \quad (15-5)$$

where

S = received signal strength (W)

$\left(\frac{\lambda}{4\pi R} \right)^2$ = space loss term ($0 < \text{space loss} < 1.0$) (unitless)

G_r = receiver's antenna gain (computed the same way as the transmitter's antenna gain) (unitless)

Notice we have a term representing space loss. *Space loss* is not a loss in the sense of power being absorbed in the atmosphere; rather, it accounts for the way energy spreads out as an electromagnetic wave travels away from a transmitting source. As distance increases, this term becomes

smaller, which means space losses get worse. This situation makes sense. The greater the distance between a transmitter and receiver, the greater the total space losses (smaller space loss term). When this term is multiplied by the transmitter's power, and the receiver's and transmitter's antenna gains, the total signal strength, S , gets smaller for longer distances.

So we now have several ways to increase the received signal

- Increase the transmitter's power— P_t
- Increase the transmitter's antenna gain, concentrating the focus of the energy— G_t
- Increase the receiver's gain so it collects more of the signal— G_r
- Decrease the distance between the transmitter and receiver— R

A few pages back we discussed the concept of signal-to-noise (S/N) ratio in communication systems. So far in this discussion we've talked about the received signal, S . Earlier, when we discussed communicating across a room, noise came from some rambunctious kids. But where does noise come from for a radio signal? One important source of radio noise is heat. Recall from our discussion of black-body radiation in Chapter 11 that any object having a temperature greater than absolute 0 K emits EM radiation. While a receiver is running, just like your TV set, it gets hot and produces EM radiation as noise. The amount of noise power is given by

$$N = kTB \quad (15-6)$$

where

N = noise power (W)

k = Boltzmann's constant = 1.381×10^{-23} joules/K

T = receiver system's temperature (K)

B = receiving system's bandwidth (Hz)

Bandwidth is the range of frequencies the receiver is designed to receive. For example, the range of human eyesight, or the bandwidth of our eyes, is about 3.90×10^{14} Hz to 8.13×10^{14} Hz, which is a bandwidth of 4.23×10^{14} Hz. This represents the small portion of the EM spectrum we can see—visible light. Note that the noise in the receiver increases as the bandwidth increases. This should make sense, because the more information a receiver attempts to receive, the more likely it'll pick up noise. Ideally, we try to reduce the receiver temperature as much as possible and restrict the bandwidth of interest to minimize the noise.

Combining Equation (15-5) and Equation (15-6), we get the signal-to-noise ratio for a radio signal

$$\frac{S}{N} = \left(\frac{P_t G_t}{k B} \right) \left(\frac{\lambda}{4\pi R} \right)^2 \left(\frac{G_r}{T} \right) \quad (15-7)$$

where

S/N = signal-to-noise ratio (unitless)

P_t	= transmitter's power (W)
G_t	= transmitter's gain (unitless)
k	= Boltzmann's constant = 1.381×10^{-23} joules/K
B	= receiving system's bandwidth (Hz)
λ	= signal's wavelength (m)
R	= range to receiver. Worst case is $R_{\max} = \sqrt{(R_{\oplus} + h)^2 - R_{\oplus}^2}$ (m), where R_{\oplus} is Earth's sea level radius, and h is the spacecraft's height above sea level (m)
G_r	= receiver's gain (unitless)
T	= receiver system's temperature (K)

Remember, for effective communication, the signal-to-noise ratio must be greater than or equal to 1.0. (The voice you hear must be louder than the background noise in the room.) To improve the S/N we can

- Increase the strength of the signal using the methods outlined above
- Reduce the signal's bandwidth—B
- Reduce the receiver's temperature—T

So far we haven't said much about changing the signal's frequency or wavelength. What effect does this have? Looking at Equation (15-7), we'd expect that increasing the wavelength would improve the S/N ratio, but remember the relationship for gain, given in Equation (15-2). The transmitter and receiver gains are inversely related to wavelength. That is, as wavelength increases (lower frequency), gain decreases. This means the net effect of increasing wavelength (decreasing frequency) is to decrease the antenna gains and thus reduce the S/N ratio. In other words, all other system parameters being equal, higher frequency gives us improved S/N. We show all these relationships in action in Example 15-2 applied to our FireSat scenario.

We must also plan what frequencies to use to avoid losses from the atmosphere and heavy precipitation.

Satellite Control Networks

Now that we've looked at the theoretical aspects of communication networks, let's look at some examples of control networks in place to support NASA and the DoD space missions. NASA has two networks for tracking and receiving data from space. The Spaceflight Tracking and Data Network (STDN) mostly tracks and relays data for the Space Shuttle and other near-Earth missions. The STDN includes ground-based antennas at White Sands, New Mexico (Figure 15-16), as well as space-based portions using the Tracking and Data Relay Satellites (TDRS) in geostationary orbits. The deep-space network (DSN) includes very large antennas (70 m in diameter), used for tracking and receiving data from interplanetary space missions. These antennas are located in Madrid, Spain; Canberra, Australia (Figure 15-17); and Goldstone, California.



Figure 15-16. Tracking and Data Relay Satellite's (TDRS) Second Terminal. This ground station controls NASA's TDRS constellation and receives telemetry and mission data from many satellites, including the Space Shuttle. (Courtesy of NASA/White Sands)

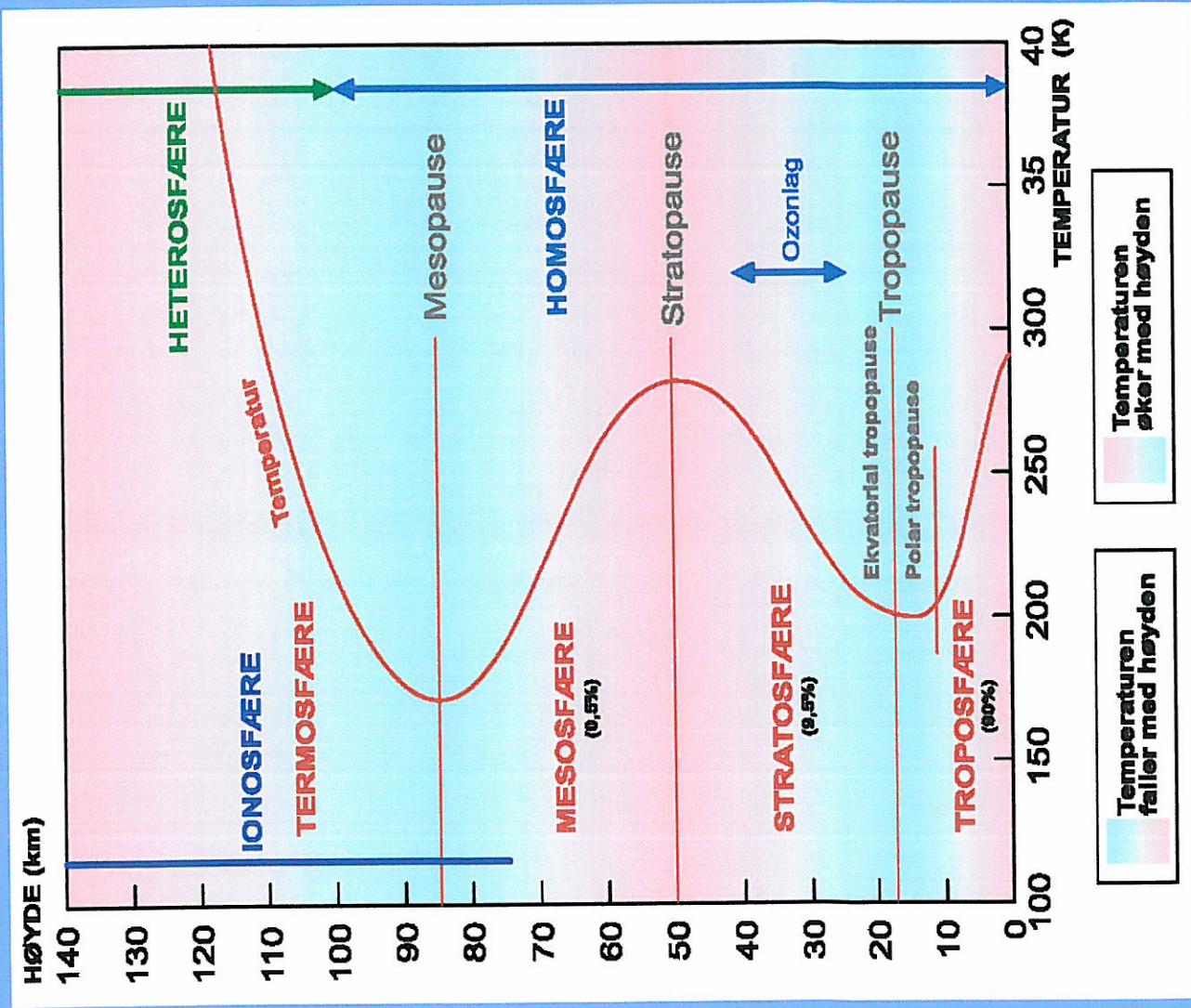


Figure 15-17. Deep Space Network (DSN). This complex of giant antennas at Canberra, Australia, keeps a constant watch for radio signals from NASA's interplanetary satellites, such as Stardust, Mars Exploration Rovers, Spirit and Opportunity, and Cassini. (Courtesy of NASA/Goddard Space Flight Center)

Type gasser	Kjemisk formel	Volum-andel av luften	Masse-prosent	Skala høyden 1 cm; Redusert tykkelse til NTP ^{a)}
Konstante gasser	Nitrogen	N ₂ ^{b)}	78,08 %	75,527
	Oksygen	O ₂	20,95 %	23,143
	Argon	Ar	0,93 %	1,282
	Neon	Ne	18,2 ppm ^{c)}	1,25 × 10 ⁻³
	Hellum	He	5,2 ppm	7,24 × 10 ⁻⁵
	Krypton	Kr	1,14 ppm	3,3 × 10 ⁻⁴
	Xenon	Xe	0,09 - ppm	3,9 × 10 ⁻⁵
		H ₂ O	0,000001 - 4 %	~ 2,5
Variable gasser	Karbondioksid	CO ₂ ^{d)}	~ 365 ppm	~ 240
	Metan	CH ₄	~ 1,8 ppm	1,1
	Lystgass	N ₂ O	~ 0,31 ppm	0,3
	Ozon	O ₃	~ 0,4 ppm	0,4
	Karbonmonoksid	CO	~ 0,09 ppm	
	Klorfluor-karbongasser	KFK	~ 0,00005 ppm	

Merknader:

- a) NTP = redusert til normal trykk (760 mmHg) og temperatur (15° C)
- b) N₂ = nitrogenmolekyl.
- c) 18,2 ppm = 0,0018 %
- d) Da CO₂ inngår i fotosyntesen, er tettheten av CO₂ mindre på sommeren enn på vinteren. Koncentrasjonen øker med > 0,4 % pr. år og har øket med 35 % siden år 1800.



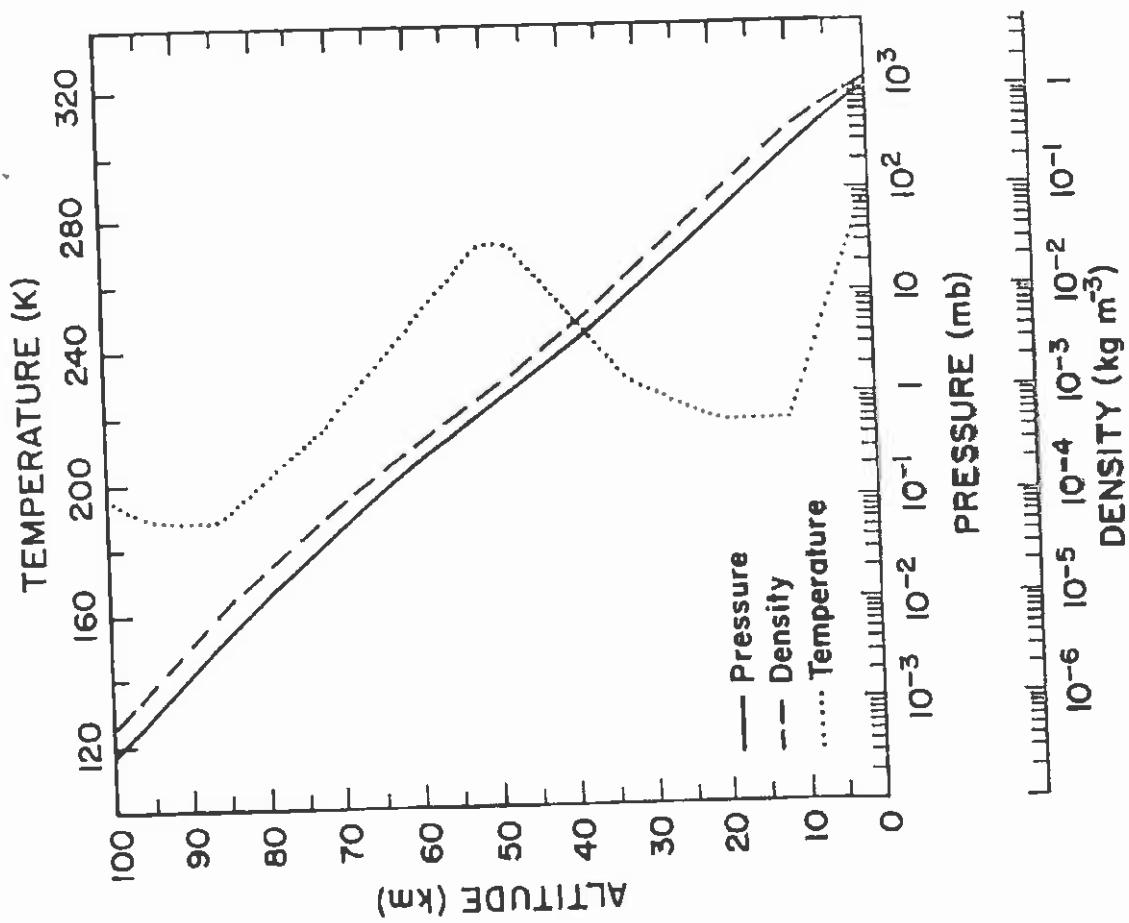


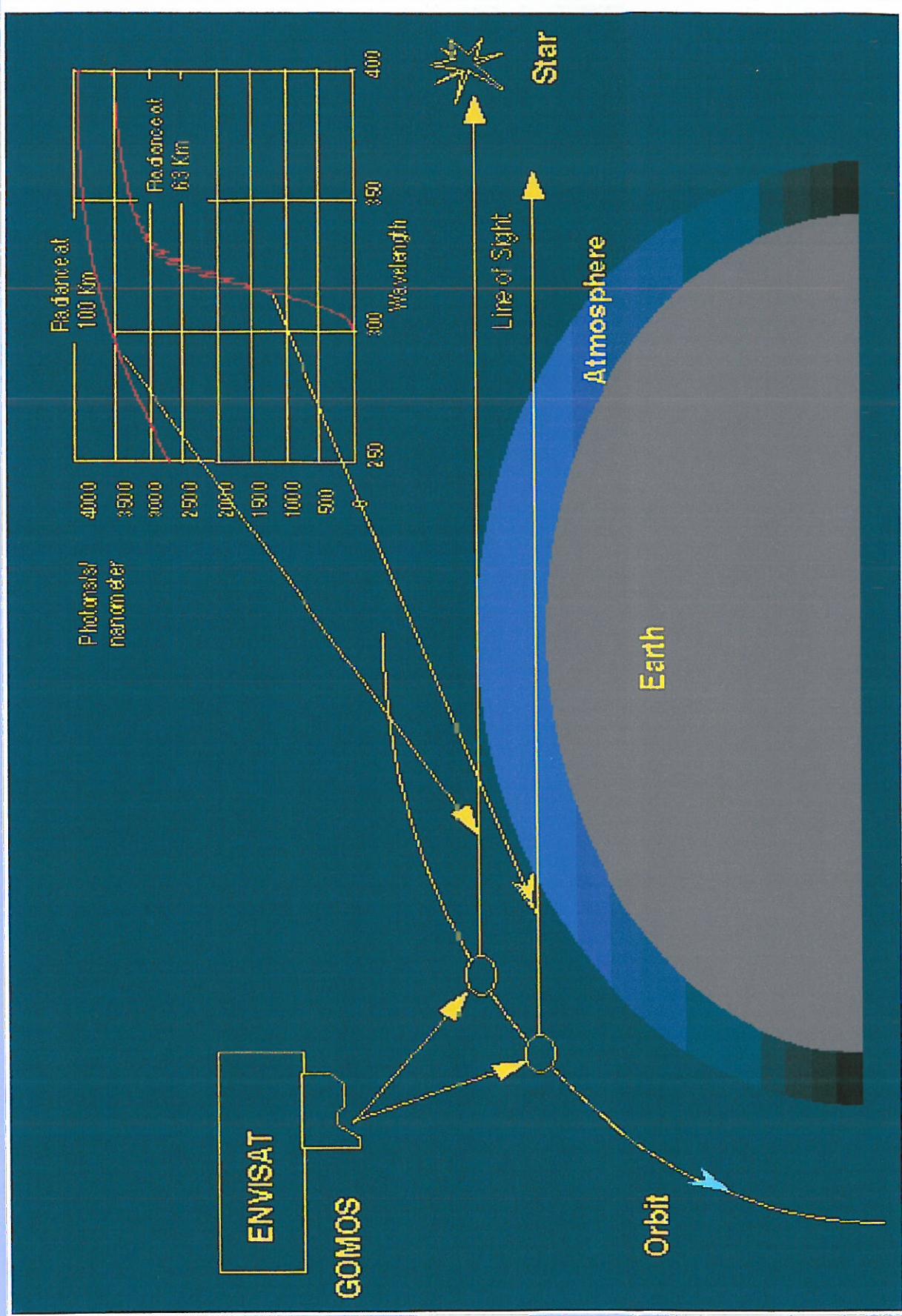
Figure 1.2 Global-mean pressure (solid), density (dashed), and temperature (dotted) as functions of altitude. Source: U.S. Standard Atmosphere (1976). Ref: Salby

Beregn en verdi på H!

- $H = k \cdot T / \tilde{m} \cdot g$

$$\begin{aligned}k \cdot T &= 1.38 \cdot 10^{-23} [\text{J/K}] \cdot 288 [\text{K}] = / \\&= 3.97 \cdot 10^{-21} \\\tilde{m} \cdot g &= 29.1 \cdot 1.66 \cdot 10^{-27} [\text{kg}] \cdot 9.82 [\text{m/s}^2] = \\&= 4.74 \cdot 10^{-25}\end{aligned}$$

- Altså $H = k \cdot T / \tilde{m} \cdot g = 8.375 \text{ km}$



$$a) mg = m \omega^2 r = GM \frac{m}{r^2} = \mu \frac{m}{r^2}$$

$$\Rightarrow \boxed{\omega^2 = \mu/r}$$

$$\Rightarrow \left(\frac{2\pi r}{T}\right)^2 = \frac{\mu}{r}$$

$$\Rightarrow 4\pi^2 r^3 = \mu T^2 \quad \text{oder} \quad \boxed{T^2 \propto \mu r^3}$$

Es wird die Bahnzeit weiter mit der Schwerpunktformel

ausgerechnet:

$$T = \frac{2\pi r}{v} = \frac{2\pi r}{\sqrt{\frac{GM}{r}}} = \frac{2\pi r \cdot 6400 \cdot 10^3}{\sqrt{24 \cdot 3600}} \approx 7 \text{ s}$$

$$c) r = \frac{p}{1 + e \cdot \cos \vartheta}$$

$r = \text{Radius}$
 $\vartheta = r$ und $\vartheta = 90^\circ$, $\vartheta = 0$ für r für monozentrische
 geplante Umlaufbahnen
 $e = \text{Exzentrizität}$

$$(p = a(1 - e))$$

$a = \text{halbe Strecken}$

$$\text{betrachten bei } \vartheta = \sqrt{\mu/\frac{2}{r} - 1} \quad \text{OK}$$

In Fig 6.3, the fuel and the oxidizer are pressurized by helium. The two components are fed separately to the combustion chambers of the apogee kick engine (AKE) and the thrusters, where they ignite spontaneously. The thrusters are used in various combinations for orbit control as well as attitude control. Only one set of thrusters is used, the other set being redundant.

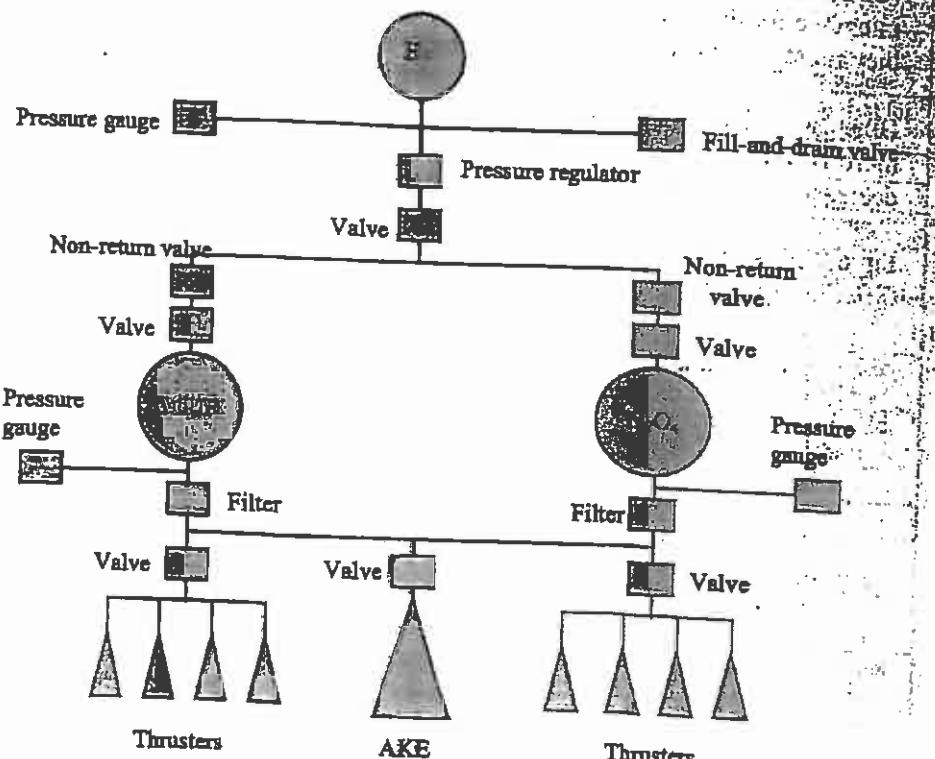


Fig 6.3: Bipropellant propulsion architecture for a three-axis stabilized satellite.

Propellant Storage

Liquid Propellants

Feeding liquid propellants from satellite storage tanks is complicated by the weightlessness of space. Where spin-stabilized satellites are concerned, the centrifugal force creates an artificial gravity which is exploited as shown to the left in Fig 6.5.

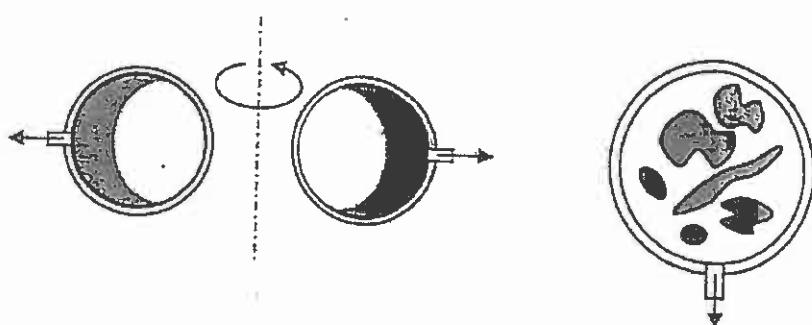


Fig 6.5: Propellant feed with and without centrifugal force.

The figure to the right illustrates the dilemma with a body-stabilized spacecraft, where the liquid's surface tension causes it to form lumps that hover inside the tank in an uncontrolled manner. Pressurizing the tank does not solve the problem, since the pressurant fills all empty spaces equally.

There are two common methods of forcing the propellant into the drain (Fig 6.6). One is to install an elastic membrane which acts as a bladder. This solution works reasonably well until the membrane is flat and the remaining propellant is trapped.

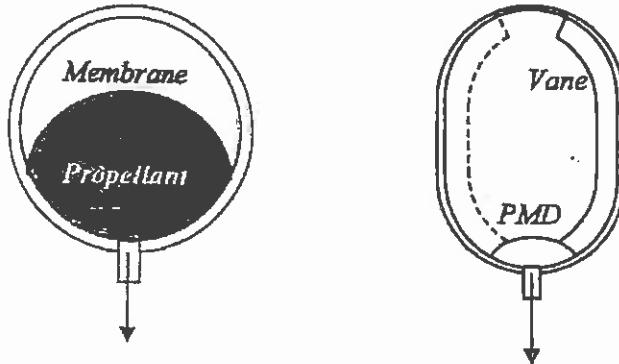


Fig 6.6: Propellant management using bladder and vanes.

The second method allows all the propellant to be drained in weightlessness. Vanes are attached to the inside wall of the tank. Surface tension causes the liquid to adhere to the vanes and work its way down to the *propellant management device* (PMD) at

one end of the tank. The PMD is basically a piece of wire mesh shaped like a clamshell, which allows liquid but not gas to filter through.

The membrane solution works well with monopropellant hydrazine but is prone to corrosion damage by the oxidizer in bipropellant hydrazine systems. The PMD is therefore the norm for the MMH + N₂O₄ combination.

Solid Propellants

Fig 6.7 shows a cross-section of a typical solid propellant AKM.

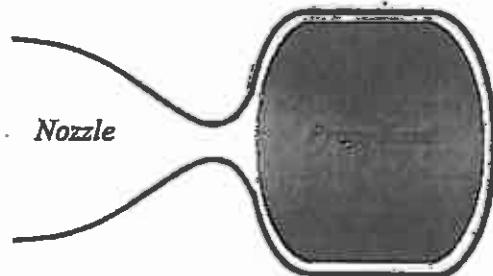


Fig 6.7: Solid propellant apogee kick motor.

Before a solid propellant AKM is filled, the inside wall of the casing is coated with a rubber-like liner which improves the adhesion of propellant to the wall and serves as

thermal insulation. The propellant is cast such that a hollow core results. The hollow provides a larger burning surface, and hence greater thrust, than a solid casting. The shape of the hollow determines the thrust profile, as illustrated in Fig 6.8.

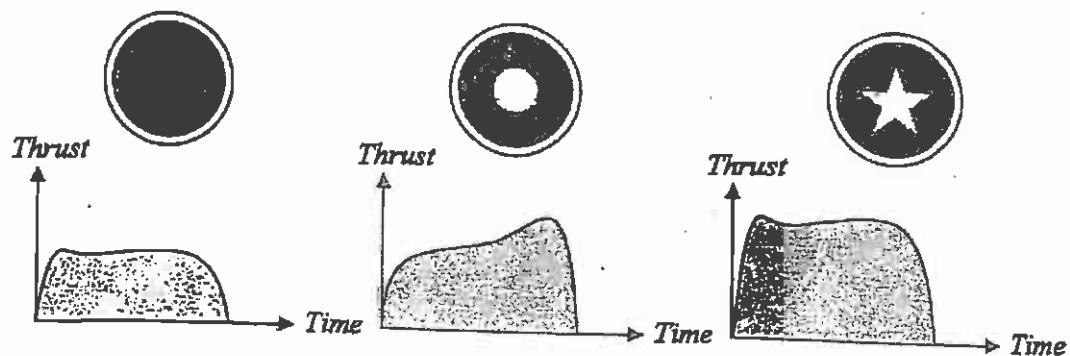


Fig 6.8: Thrust profiles as a function of core geometry,
as seen from the nozzle end.

A solid casting will give approximately constant thrust, which is preferred in most missions (see left figure), but the exposed surface is too small to yield adequate thrust level. By drilling or casting a cylindrical hole through the centre, we achieve a larger burning area and therefore greater thrust. But as the combustion erodes the walls of the hole, the burning area becomes larger, and the thrust grows with time (see dotted contour of the middle figure). This may or may not be a desirable side effect.

Electrodynamic Propulsion (EP)

Several electrodynamic thruster technologies have been developed over the last 20 years, inspired by the promise of extremely low propellant consumption for a given total impulse compared to the thermodynamic alternatives.

There are three classes of electric thrusters: *electrothermal*, *electrostatic* and *electromagnetic*. In the electrothermal variety, thrust is generated by electrically super-heating neutral gases. In electrostatic and electromagnetic thrusters, a neutral gas or solid is electrically ionized, and thrust is created by accelerating the ions by means of an electrostatic or electromagnetic field.

Each type of EP thruster is divided into sub-groups depending on the adopted design solution. Table 6.2 summarizes the main characteristics of the various solutions. Not all of these are, or ever will be, suitable for earth-orbiting satellites. They are nevertheless included for the sake of completeness.

PROPELLANTS

Single component fuel

	Typical $I_{sp}(s)$	Thrust (N)
Cryogenic nitrogen	75	0.1 - 250
Solid fuel	210 – 290	100 - 10^6
Hydrazine N ₂ H ₄	220 – 300	<1

Two component fuel

Kerosene + O ₂	300 – 350	10 - 10^6
UDMH + N ₂ O ₄	300 – 350	10 - 10^6
MMH + N ₂ O ₄	300 – 350	0.1 - 500
H ₂ + O ₂	440 – 460	10 - 10^6

Ion propulsion

	2000 – 4000	approx 20 - 200 mN
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Losungen für die appr. 3s

$\Delta v_{2, \text{trim}}$ setzt vorst

$$\Delta v_{2, \text{trim}} = I_{\text{sp}, 2} \cdot g_0 \cdot \ln \left(\frac{m_{\text{struktur}_2} + m_{\text{Meinstoffe}} + m_{\text{Payload}}}{m_{\text{struktur}_2} + m_{\text{payload}}} \right)$$

$\Delta v_{1, \text{trim}}$ ist da $\Delta v_{\text{design}} - \Delta v_{2, \text{trim}}$

Startmassen fah zu fra

$$\Delta v_{1, \text{trim}} = I_{\text{sp}, 1} \cdot g_0 \cdot \ln \left(\frac{m_{\text{start}}}{m_{\text{struktur}_2} + m_{\text{drivstoff}_2} + m_{\text{struktur}_1} + m_{\text{payload}}} \right)$$

$$\begin{aligned} \Delta v_{2, \text{trim}} &= 400 \cdot 9,81 \cdot \ln \left(\frac{12000 + 2000}{3000 + 2000} \right) \\ &= 400 \cdot 9,81 \cdot \ln (3,80) = 4040 \text{ m/s} \end{aligned}$$

$\Delta v_{1, \text{trim}}$ ist da $\Delta v_{\text{design}} - \Delta v_{2, \text{trim}} = 5960 \text{ m/s}$

$$5960 = 350 \cdot 9,81 \cdot \ln \left(\frac{m_{\text{start}}}{3000 + 9000 + 2000 + 8000} \right)$$

$$1735 = \ln \left(\frac{m_{\text{start}}}{22000} \right)$$

$$m_{\text{start}} = e^{1735} \cdot 22000 = 139535 \text{ kg}$$

$$m_{\text{drivstoff}} = 139535 - (8000 + 12000 + 2000) = 117535$$

$$\frac{\text{payload}}{\text{start massa}} = \frac{2000}{139535} = 0,0143 = 1,43\%$$