PETROLEUM ECONOMIST

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UK NORTH SEA SURVEY

PAPUA NEW GUINEA

OIL FIND RAISES

PRODUCTION HOPES

West Germany's energy balance

OIL COMPANIES

Report on a turbulent year

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Strategic significance of jet fuel - Part II

by Tom Cutler

This concludes the article, which began in last month's issue, on the history of jet fuel development and its rise to prominence as the petroleum product most widely used by military forces.

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AN important milestone was reached on 15 May 1941 when a Gloster E.28/39 became the first Allied jet to fly but the project was soon disrupted by German air raids. Given the priority associated with this now jeopardised effort, London decided to bring the Americans in on their work so that back-up development and production facilities located in the United States could be established.[1]

In the spring of 1944 Germany began to target British cities with an onslaught of V-1 "flying bombs" (propelled by a jet engine atop the fuselage with 130 gallons of fuel) and V-2 ballistic rockets (fuelled by a combination of 5 tons of liquid oxygen, 4 tons of alcohol, 375 pounds of hydrogen peroxide, and 25 pounds of sodium permanganate). Other than to destroy their launching sites, there seemed to be no defence until the RAF's Gloster "Meteor" jet entered service later in the year. Because it was the only Allied plane whose speed on level flight could come close to matching the jet-propelled missiles, its first operational role was to defend against these "flying bombs." Five Meteors were deployed for this purpose and on 4 August 1944 a V-1 crashed and burned after a Meteor had daringly brushed it with its wingtip.

Germany in the meantime, in desperate need of a way to defend against the devastating Allied bombing raids, had been forced to redesign its original Jumbo 004-type jet engine with simpler metallurgy since its high content of scarce strategic materials (*e.g.* cobalt and molybdenum) had precluded mass production. The much delayed entry into combat of the Me 262A-1a Schwalbe ("Swallow") proved successful in intercepting Allied bombers; air crews of US B-17s and B-24s were surprised by propeller-less German jet fighters traversing the skies at then incredible speeds in excess of 500 mph (this was 100 mph faster than the best Allied fighter although in a dive one model of the American P-47 could catch the Me-262). Threatening to dominate the air war, the Me-262 became such a menace to US daylight bombing raids that the Meteors were temporarily recalled from combat duty and flown in mock tactical exercises with B-17s to see if a method for countering the German jets could be found. It was soon apparent that there was no effective aerial defensive strategy and so shortly before the end of the war two squadrons of Meteors were reassigned to ground strafing in support of the Allies' drive across Europe to Berlin.

Fate intervened at this critical stage when Hitler himself ruled against his advisers who recommended a step-up in Me-262 output. In what some regard as a grievous strategic error, he dictated that it be converted into an offensive bomber instead even though the Me-262 could be modified for bombing purposes by outfitting it with twin bomb pylons. Moreover, the Luftwaffe already operated the more effective Arado Ar 234 B Blitz ("Lightning"), the world's first jet bomber. Due to Hitler's reticence, the Luftwaffe could muster no more than 50 Me-262s in March 1945 to counter the massive Allied attacks whose destruction of Germany's synthetic jet fuel factories severely incapacitated the nation's fighting capability and was instrumental in drawing hostilities to a close. (In the war's Pacific theatre no jets ever flew as Japan surrendered before it, *i.e.* Mitsubishi, could begin producing its own jet plane. This was based on drawings and sample Jumbo 004 engines delivered from German-occupied France by submarine in a six-month voyage beneath the sea).

Post-War evolution

Germany's status as the world's leading innovator in the application of jet propulsion to military aviation ceased with its defeat and as a nation it no longer played a significant role in jet fuel development. However, the wartime momentum of military-sponsored research and development in jet propulsion and fuels technology did not abate in the post-war period. The breaking of the sound barrier in 1947 and the advent of supersonic flight heralded a new generation of sophisticated jet fuels. For example, the Bell XS-1 which USAF Captain Charles Yeager piloted to the speed of sound (764 mph) on 14 October 1947 was fuelled with 288 gallons of liquid oxygen mixed with a 300 gallon blend of five parts alcohol to one part water. This 600-gallon fuel supply was depleted at peak thrust within $2\frac{1}{2}$ minutes but, in fact, the XS-1 never landed with any fuel on board anyway since its fragile landing gear was not designed to bear the extra weight. The supersonic jets that followed possessed high-performance engines of such thrust that flight speeds were limited by aerodynamic considerations and not engine power. As a result, by the late 1940s fighters were being designed with swept back wings modelled after German research findings from the war. Perhaps the most imaginative endeavour was America's successful operation in 1954 of a GE-constructed jet engine powered by nuclear fuel. In any event, for the superpowers, scientific efforts to identify the optimum mix of fuel properties for maximising fuel combustion and engine thrust resulted in a proliferation of different types of military jet fuels, distinguishable by specifications uniquely tailored to various kinds of specialised missions (see Table in Part 1 of this article, published in the May issue *of Petroleum Economist*).

At the same time, jets were being readied for commercial purposes as passenger planes, and on 2 May 1952 the British Overseas Airways Corporation inaugurated the first scheduled jet service by flying the 36-passenger de Havilland "Comet" from London to Johannesburg via Rome, Beirut, Khartoum, Entebbe, and Livingstone. However, in contrast to the trends in military jet fuels, only two types of jet fuels have been utilised by civil aviation, both kerosene based and differing only in their freeze-point (*i.e* Jet-A and its derivative form Jet-A1). Jet-A's origins date back to quality guidelines issued by the British government in 1947 which became internationally accepted standards in 1958. Specifications for Jet-A1 were issued in 1959 stipulating a lower freeze-point due to problems of ice formation and fuel system clogging with Jet-A. Since then, the standard international jet fuel for civil aircraft has traditionally been Jet-A1; demand for Jet-A has been limited almost exclusively to airlines operating domestic routes in the US. From their inception, kerosene jet fuels have been routinely accepted by most military users with the notable exception of the US whose preference for gasoline/naphtha-based jet fuels has meant that in both the civil and military arenas, US aviation has pursued a somewhat independent course in the selection of fuels it uses.

In the military context, the US initially used kerosene-based jet fuels as a result of its wartime collaboration with the British; specifications for its first jet fuel, JP-1 published in 1944, stipulated kerosene components. But problems in JP-1's supply availability made gasoline-based jet fuels an attractive alternative due to the high gasoline yield from America's domestic crudes and gasoline's lower cost, as well as advantages of greater combustibility, ignition characteristics, and low temperature properties. Thereafter, the US preference for gasoline-based jet fuels became a matter of policy as a series of wide-cut blends were tried before JP-4 was introduced in 1951 as the official military jet fuel. (It should be noted that in 1952 the US did issue specifications for a high-flash-point, kerosene-based jet fuel designated JP-5 for use by its carrier based aircraft). JP-4 has since become the most commonly used militarily unique fuel in the world, due to the preponderance of American-made military jets in its own inventories and those of nations friendly to it.

While World War II offered opportunities for the British and the Germans to assess the performance of their respective kerosene and diesel based jet fuels, albeit only in the waning months of fighting in the European theatre, the US had no combat experience whatsoever with its gasoline jet fuels until the Korean conflict of 1950-53 where for the first time jet warplanes were used extensively by both sides. For the US, JP-4 performed well as its cold start and relight properties were ideally suited to the frigid conditions experienced in Korea. Years later, however, a different assessment of JP-4 emerged in tropical Viet Nam where the extensive use of helicopters and aircraft for close ground support revealed the dangers of JP-4's volatile gasoline compounds. The low altitudes at which most sorties were flown fatally exposed US aircraft to small calibre gunfire from the ground, and many helicopters and planes were lost as fuel tanks erupted into flames when punctured by bullets. Fuel fires and explosions during ground handling were prevalent and constituted an unacceptable vulnerability for depots threatened by Viet Cong mortar attacks. The situation finally became so hazardous that in 1967 the USAF Tactical Command formally requested that JP-4 be replaced by a safer fuel.

At the outset Jet-A was eliminated from contention due to its high freeze-point, but Jet-A1 (JP-8) was considered to be a promising prospect even though it, too, was susceptible to possible freeze-up and slower transfer rates during in-flight refuelling due to its freeze-point. There followed a comprehensive series of feasibility tests to compare the technical properties and operational performances of JP-4 and JP-8.

Volatility is an important indicator of a fuel's starting properties inasmuch as petroleum fuel is ignited as a vapour and not in its customary liquid state. Although high volatility facilitates cold starts and engine relight, particularly at high altitudes, military jet fuel must also include blends of low volatility components. At high altitudes, reduced atmospheric pressure lessens air's solubility in fuel, causing dissolved air to be expelled in the form of fuel vapours which literally boil off. This can result in significant fuel losses. These problems can be controlled by pressurised fuel tanks; alternatively, the cold temperatures encountered at high altitudes are often sufficient to offset vapourization and alleviate fuel boil-off (but this applies to sub-sonic speeds only since the opposite effect of extreme heat is experienced at supersonic speeds). Beyond Mach 1, rapid air flow generates frictions which kinetically heat aircraft surfaces (and hence the fuel), thereby exacerbating high altitude vapourization. Thus, beyond the speed of sound, JP-8 is more desirable than JP-4 in terms of fuel stability while JP-4's advantages are most prevalent at subsonic speeds.

Defined as a fuel's energy content per unit of volume, energy density is an important consideration in calculating a fuel's energy output. High energy density fuel offers greater energy output per volume while a low energy density fuel gives more energy per unit weight. Low density fuels are generally preferred for combat operations, especially for fighters and tactical bombers carrying heavy loads of munitions, because they are constrained by weight limitations at take off. Comparisons of the two fuels calculated that a jet filled with 3 000 gallons of JP-8 would be burdened by 1 000 more pounds of fuel than if JP-4 was used due to differences in specific gravity, and that this could reduce performance during high speed interception or strike missions. On the other hand, JP-8's higher calorific value by volume could extend the range of a mission by 3-5% when the payload was light and, from a procurement standpoint, would be a better buy on a dollar per BTU basis when purchased by the gallon, cubic metre, or barrel. (Cruise missiles benefit most from high density fuels because they are volume limited. These exotic fuels are very expensive and are difficult to handle and store since they freeze solid at normal temperatures).

Synonomous with the enhanced fuel safety sought by the US was a reduction in fuel fires associated with JP-4's inordinately low flash-point of -20F even though flash-point was not regarded as the primary determinant of flammability with respect to combat survivability. Rather, the relationship between "impact" and volatility was regarded as crucial since in war military crashes are invariably caused by being hit in mid-air by projectiles or occur during take off and landing. Petroleum fuel in its liquid form does not of itself ignite into flame, instead it is fuel spray and associated vapours generated by the impact of collisions that ignite fireballs which destroy aircraft and kill crews. Research concluded in 1968 that there was little that could be done to reduce JP-4's volatility in terms of vapourization and flame propogation, while the less volatile JP-8 could be made even safer through the use of gels and anti-misting additives. Since JP-4's operational advantages were not seen to be sufficient to justify its retention, it was recommended that JP-8 be adopted as a standard USAF jet fuel. As it turned out, JP-8 was never used for US air operations in Southeast Asia but it was not long before the US turned its attention to NATO where both JP-4 and JP-8 were used and where, after the oil crisis of 1973, concerns over fuel cost and availability were becoming as important as chemical and physical properties in the choice of military jet fuels.

NATO jet fuel conversion

Following the American assessment that JP-8 was a desirable fuel, it was not until 1976 that NATO Defence Ministers agreed that (1) all future land-based military aircraft should be designed to operate on JP-8; and (2) assessments should be made of the feasibility of adopting JP-8 as the standard NATO fuel for existing land-based aircraft, including conversation of storage facilities. At that time, only France and the UK used JP-8 for their military jets, leaving NATO's other members with the option of either modifying their existing fleets or continuing to use JP-4. Following the 1979-80 Iranian crisis, concern over increased fuel acquisition costs became the most divisive issue in reaching a consensus as JP-8 was cheaper than JP-4 in some nations but more expensive in others by differentials of up to 7 cents per gallon. There ensued years of arduous negotiations under the jurisdiction of the NATO Pipeline Committee, culminating in the May 1986 announcement that all nations had agreed to convert and that the switch to JP-8 was now an Alliance-wide commitment.

Conversion will be phased in a series of increments since it will take some nations up to two years at current levels of consumption just to deplete their existing inventories of JP-4. The NATO Pipeline System will also undergo other modification and extensive retrofitting in conjuction with conversion, and at various locations icing inhibitor injection systems will be installed. Upon completion of the conversion process the safety of ground fuel operations will be enhanced, particularly during hot refuelling (loading fuel in aircraft while at least one engine is running), switch loading (changing fuel types carried by refuelling vehicles), in-shelter refuelling, the simultaneous loading of fuel and munitions, and purging aircraft tanks of flammable vapours in preparation for hanger maintenance. In the end, it is believed that the millions of dollars spent on modernising the NATO Pipeline System will prove to have been cost effective.

Cost impact uncertain

Even though the conversion programme's phasing-in period includes formal notification to refiners to ease disruptive impacts on the market, considerable uncertainty persists as to what repercussions will be felt by the commercial sector. What is clear is that the switch to JP-8 by US forces will have potentially more impact upon European jet fuel supply/demand balances - and, hence, price reactions - than any other single country, due to the size of its anticipated requirements. Nearly half of the approximately 50 000 b/d of JP-4 demanded by NATO military users in Europe is consumed by US forces stationed there - but, significantly, not all of this amount is necessarily purchased there. Whereas European refiners have enjoyed a virtual monopoly in supplying European country JP-4 needs, there has been a recent, major shift in the sourcing of US JP-4 requirements for reasons of price that raises questions as to where the NATO countries, but particularly the US, will be getting their JP-8 over the next few years.

Under the "Atlantic/Europe/Mediterranean Purchase Program" of the Defense Fuel Supply Centre (DFSC), the purchasing agent for all US military oil needs, US forces assigned to NATO Europe obtained most of their JP-4 from Southern European refiners during the early 1980s. This supply pattern changed abruptly in 1984-85 as US purchases of locally processed JP-4 plummeted to 24% of requirements with the remaining supplies acquired from sources in the Western Hemisphere. To the extent that these refiners in the Caribbean and along the US Gulf Coast can also serve as equivalent sources of JP-8, the US may have sufficient flexibility in its purchases of JP-8 so as to moderate any undesirable impacts on European markets by virtue of its diversity of supply. At the same time there is considerable potential for European refiners to develop new business opportunities by selling JP-8 to US forces, providing thay can compete on the basis of price. It would be too speculative to make any conjectures at this point as to what the future will hold although a very useful market study by the US Department of Defense (DOD) in 1985 addressed the issue of what impact NATO's conversion to JP-8 would have upon European demand for Jet-A1 through an analysis of three possible supply scenarios.

It estimated that total NATO demand for JP-8 from European refiners might increase by 23 000 b/d, to 41 000 b/d, of which the US increase could range from 4 000 B/d to 23 000 b/d.

For technical reasons, relative price levels among oil products may also be influenced by conversion. For example, increases in commercial demand for leaded gasoline would in theory have less effect upon military jet fuel costs in the post-conversion context than it would beforehand since JP-4 comes from that same part of the barrel while JP-8 does not (being distilled solely from the kerosene cut). However, European country compliance with the EEC edict to phase-out leaded gasoline, and the expected demand for naphtha as a reforming feedstock to make unleaded gasoline, may well tend to increase price levels for products produced from the JP-4 cut of the barrel. The refining processes utilised to manufacture either JP-4 or JP-8 both rob the refiner of some reformer feedstock which diminishes the capability to make a high octane component of unleaded gasoline. However, making JP-4 requires more reformer feedstock than does making JP-8. Thus, cutting back on the use of JP-4 will make it easier for refiners to produce unleaded gasoline by virtue of the greater availability of unutilised reformer feedstock. This should have the effect of easing price pressures on unleaded gasoline.

The market outlook will be further complicated if the proposal to introduce JP-8 as a ground fuel in NATO Europe for military vehicles in place of gasoline and diesel fuel is adopted by the NATO armies. In this situation, the relative proportion of oil products which refiners must produce to meet the demands of European consumers will be skewed by reduced requirements for gasoline and diesel fuel. Moreover, using JP-8 for ground fuel purposes in lieu of diesel fuel could result in upward pressures on unleaded gasoline prices since, unlike JP-8, making diesel fuel does not normally affect production of maximum yields of unleaded gasoline and because hardly any reformer feedstock is utilised in its manufacture. On the other hand, since gasoline comes from a distilliate fraction similar to JP-4's, conversion to JP-8 could very well serve to offset price pressures on unleaded gasoline. As a result of these two opposing factors, and in conjunction with other considerations, it is difficult at this juncture to predict what conversion's price impact would be. The bottom line is that refiners will obviously have to be prepared to make some adjustment in the slate of products they produce to accommodate resultant shifts in demand across the barrel while, concomitantly, commercial airlines in Europe may well encounter increased fuel costs as the military sector comes into even more direct competition for Jet - A1/JP-8.

Questions of supply availability

The supply availability advantages of conversion are of a short term nature only, such as in those instances where the military needs to access commercial stocks immediately for emergency resupply. Over the longer term, where refiner producibility and not inventory levels are the key, the implications for jet fuel supply availability by converting to JP-8 are potentially disadvantagous. This is because the maximum production potential of JP-8 is inherently limited by the narrow cut of the barrel from which it is distilled. Depending on the crude stream and processing configuration, the maximum yield possible from a given barrel of crude for JP-8 could be as little as one-fourth of that for JP-4. That refinery yield constraints *per se* would cause serious shortages of JP-8 as a consequence of conversion is an unlikely possibility over the next decade, even under the most extreme circumstances, according to studies conducted by NATO's Advisory Group on Aerospace Research and Development in collabortion with Exxon and the US National Aeronautics and Administration.[2]

While stocks of commercial Jet-A in the US are not militarily useful, US refiners do have the technical capability to produce Jet-A1/JP-8 as suppliers of last resort for Europe in the event of militarily-threatening shortages in war time. In the worst case scenario, of course, the military could revert its aircraft and logistics systems back to JP-4 and arrange for refiners to readjust their yields accordingly. This option was analysed in 1980 by the US Department of Defense which estimated that European refiners could theoretically process 2-2½ times more JP-4 than JP-8/Jet A1 from a representative crude barrel, while refiners in the US could produce 2½ - 3 times more JP-4.

Even though US experiences in Viet Nam helped convince NATO officials that JP-4's volatility posed unacceptable risks for war, it should be noted that JP-8's extra margin of combat safety in reducing aircraft attrition and crew casualties would tend to be less in a NATO context than in Southeast Asia. This is because the conventional order of battle likely in a NATO war and the weaponry used would pose few situations where fuel would be a determining factor in aircraft survival. Whereas US forces in Viet Nam relied heavily upon helicopters to transport troops and supplies across mountains and jungle, Europe's topography would allow for greater use of ground vehicles. Moreover, they would be able to operate along more conventionally structured front lines while in Viet Nam there were virtually no secure sanctuaries. In a NATO war the greater use of sophisticated surface-to-air and air-to-air missiles would be such that upon being hit, fuel type would hardly matter. In sum, for NATO there are significant advantages to conversion with safety and interoperability perhaps being the most important considerations whereas supply availablity could be a disadvantage in time of war.

Future jet fuels

Throughout their 50 years of existence military jet fuels have been subjected to increasingly stringent quality requirements due to meteoric advances in aviation and propulsion. As a result, combustion characteristics, while still important, no longer constitute the overriding factor in the determination of the necessary fuel properties demanded by supersonic craft in military fleets (with few exceptions civilian planes rarely exceed Mach I). Under the harsh operating conditions of supersonic flight, the role of jet fuel expanded beyond simply that of a combustion agent for propulsion to that of a heat sink for the airframe and avionics systems, requiring heretofore unknown advances in thermal stability. When utilised as a heat sink, stable high temperature properties are required as the fuel is circulated throughout the airframe to act as a coolant for electronic equipment, hydraulic oil and engine oil - and, in some cases, to control cabin air temperatures as part of the plane's air conditioning systems.

Formulation of a jet fuel with the the optimum mix of properties entails compromises between the competing requirements of the engine and airframe, and reflects the constraints imposed by limitations of fuel technology and supply economics. Stealth fighters and bombers designed to be undetectable by radar will possibly require fuels with restricted exhaust emissions and combustion signatures consistent with tactical invisibility. While somewhat speculative, this aptly illustrates the kind of unusual choices confronting the military, *i.e.* the extent to which fuel capabilities should dictate engine and aircraft design, or, conversely, to what extent must new, exotic and probably expensive fuels be developed to suit the needs of the military aircraft of tomorrow.

Although it will likely be some time before hypersonic aircraft (faster than Mach 5) enter military and commercial fleets, the technological challenges in developing suitable hypersonic fuels may well dwarf the accomplishments in jet fuel research that accompanied the transition from sub-sonic to supersonic flight. It is inevitable that a host of new parameters for fuel will become essential as the aerodynamic forces encountered impose incredibly severe stresses upon the sructural integrity of the aircraft. Many of the combustion and thermal properties required will be so extreme that for all practical purposes they will be mutually exclusive to the point where they cannot be combined within one petroleum fuel.

Conventional jet fuels, advanced hydrocarbon fuels, and even the use of endothermic fuels (which undergo a heat-absorbing chemical reaction) are not seen by some experts to be practical for hypersonic flight because of insufficient heat sink capabilities and unacceptable thermal degradation at the high temperatures to be encountered. Nor are powdered slurry fuels, especially those of the boron type, regarded as feasible due to their toxicity. Some expect that cryogenic fuels (characterised by boiling points below —150F) are the most likely candidates. According to this point of view, the first hypersonic fuel will be composed of methane with hydrogen becoming attractive sometime in the next century as further increases in military flight speeds move mankind into the unknown realm of the seemingly impossible. □

FOOTNOTES

1 Jet engine efforts in the US had lagged considerably behind the work in Germany and Great Britain. In 1938 the US Navy had become interested in turbojets but the high level advisory group tasked to assess its potential, the National Advisory Commitee on Aeronautics, issued a negative report on the feasibility of turbojets for aircraft propulsion because of their weight and advised that the most promising applications were for naval ships. Following the British initaitive in October 1941, the USAF secretly tasked General Electric (on the basis of its established expertise in turbochargers) to develop an American jet engine. By April 1942, GE had tested its first prototype engine based upon samples provided by Whittle and on 2 October 1942 a Bell XP-59A became the first US jet to fly.

2 These studies also found that increased costs and refiner output limitations due to conversion could be mitigated by relaxation of military fuel specifications and/or refiner utilization of processed feedstocks (e.g cracked products) to produce jet fuel. It was concluded that the relaxation of aromatics or freeze-point in particular, or the inclusion of cracked stocks, would increase the output of jet fuels by up to a factor of three while at the same time reducing costs.

Continued decline in US earnings

The leading US oil companies have reported a slide in profits during this year's first quarter, thus extending the downturn which began in fourth-quarter 1986. Despite the rally in crude oil prices from mid-1986 lows of barely $10 a barrel to around $16 in January-March, they were at that stage still well below the year-earlier level of $18.50; and that alone meant that upstream earnings were somewhat depressed. But the situation was far worse downstream for most integrated concerns. There, the squeeze on margins due to rising crude oil acquisition costs led to steep falls in earnings or even to net losses, in striking contrast to first-quarter 1986 when unusually strong margins prevailed due to the time lag which delayed falls in product prices in the wake of crude.

US OIL COMPANIES: NET INCOME

Million dollars

	1986	1987	*% change*
Amoco	331	260	*-21*
Chevron	377	198	*-47*
Exxon	1 710	1 070	*-37*
Mobil	440	252	*-43*
Texaco	328	118	*-64*
Subtotal, 5 majors	3 186	1 898	*-40*
Amerada Hess	(-339)	182	*...*
Atlantic Richfield	299	239	*-20*
Kerr-McGee	22	20	*-9*
Occidental Petroleum	74	97	*+31*
Pennzoil	(-16)	12	*...*
Phillips Petroleum	96	(-32)	*-133*
Shell Oil	276	108	*-61*
Standard Oil	253	200	*-21*
Sun Co	146	38	*-74*
Subtotal, 9 others	811	864	*+7*
Total, 14 companies	3 997	2 762	*-31*

These factors were most marked in the case of Texaco, reporting an overall drop of 64% in net income from $328m to $118m. That company's US exploration and production earnings declined to $41m from $75m for the same period of 1986; but its US manufacturing and marketing operations had a loss of $55m against earnings of $39m previously. Abroad, lower operating expenses and reduced taxes helped to improve its upstream earnings from $108m to $163m, but its downstream earnings were significantly lower at $61m against $262m in first-quarter 1986. The largest group, Exxon, noted lower earnings from exploration and production, but cited depressed refining margins as the main adverse factor in its greatly reduced downstream earnings which featured a loss of $38m against earnings of $160m in the USA and a steep fall from $440m to $874m abroad.

Exxon's overall net income was down 37% on balance, at $1.07bn. Chevron, down 47% at $198m, similarly reported reduced operating earnings in most sectors apart from chemicals. Mobil, with a 43% decline to $252m, blamed lower downstream margins due to rising crude prices and high inventories of petroleum products; but it scored gains in foreign exploration and production, chemicals and retail manufacturing. Amoco, smallest of this group in terms of assets, came out the best with a year-on-year drop of only 21% to $260m; and that represented a marked recovery from the $165m earned in fourth-quarter 1986. It also featured record earnings for chemicals, a bright spot for several of the companies reporting.

Most of the other nine companies tabulated here reported lower earnings, for much the same reasons as the majors. Only one (Phillips) showed a net loss, and that was due to a combination of lower prices and steep falls in its production volumes for both oil and natural gas. Against the trend, Occidental's income improved by $23m to $97m, but that included an extraordinary gain of $20m from carrying forward a capital loss to offset capital gains; and its results also included after-tax gains of $103m from the sale of certain chemicals operations compared with only $24m in after-tax gains last year. It may be noted that Amerada Hess and Pennzoil both staged a positive turnround from loss to profit. The former claimed improved earnings from refining and marketing and an extraordinary credit on loss carry-forwards; but Pennzoil's apparent recovery was due solely to comparison with a 1986 first-quarter in which it had made a charge of $58m on write-downs. Its pre-tax income was down by two-thirds this time.