CLIMATE RISKS AT THE HEADWATERS OF THE AEROSPACE SUPPLY CHAIN

Implications for the Availability of Critical Materials

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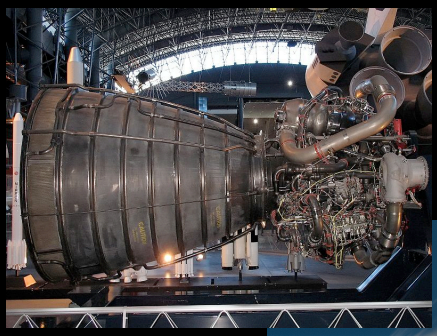
What I will discuss today

- Some minerals that are important to aerospace
- Sources of these minerals
- Potential availability risks arising from climate change
- Risk mitigation approaches

Demanding aerospace systems



High strength but low weight

High strength at high temperatures

High Performance Aerospace Engineering Alloy Compositions

Alloy	Cr	Co	Mo	W	Nb	Ti	V	other
Inconel 718	19.0	-	3.0	-	5.1	0.9	-	18.5 Fe*
Rene 41	19.0	11.0	10.0	-	-	3.1	-	1.5 Al*
Nimonic 80A	19.5	-	-	-	-	2.4	-	1.4 Al*
Waspaloy	19.5	13.5	4.3	-	-	3.0	-	1.3 Al*
Udimet 720	17.9	14.7	3.0	1.3	-	5.0	-	2.5 Al*
Ti-6Al-4V	-	-	-	-	-	90	4.0	6 Al
304 S.S.	18	-	-	-	-	-	-	8 Ni, bal. Fe

Values are percentage by weight (i.e. weight percent)

* balance Nickel

Ref. Watson and Taminger, Defense Manufacturing Conference, 2011. Original source data for all except Ti-6-4 and 304SS: Pollock, T.M. and Tin, S., "Nickel-Based Superalloys for Advanced Turbine Engines: Chemistry, Microstructure, and Properties," Journal of Propulsion and Power, Vol. 22, No. 2, March–April 2006, pp. 361 - 374.

Sources of the key alloying elements

	Top Current Sources*	Major Reserve Locations						
		Brazil	China	Russia	South Africa	Rep. of Congo	Kazakhstan	Cum. % of Known Reserves
Cr	South Africa India, Kazakhstan,				X		X	95
Co	Congo, Australia, China/Russia/ Zambia					X		45
Mo	China, U.S., Chile		X					43
W	China, Russia, Canada		X					61
Nb	Brazil, Canada	X						97
Ti	South Africa, Australia, Canada		X					30
V	China, South Africa, Russia		X	X	X			99

Red indicates predominant source

* Worldwide sources – not just U.S. sources

Reserves: That part of the reserve base which could be economically extracted or produced at the time of determination.

Source: USGS, Mineral Commodity Summaries 2012

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Good news

- At current worldwide consumption rates, most of these minerals are projected to be available for decades to centuries.*
- Therefore, we are not imminently approaching Malthusian limits.

*Kesler, S.E., 2007, Mineral supply and demand in the 21st century: U.S. Geological Survey Circular C 1294, pp. 55-62.

Bad news

- There may be other threats to future availability
- Climate change could create conditions that limit access
  - Increased prices *(example – Cobalt price increased 380% from 1977 to 1979 due to conflict in Congo*)*
  - Decreased availability

*Alonso *et al*, "Materials Availability and the Supply Chain: Risks, Effects, and Responses," MIT report, accessed at: http://hdl.handle.net/1721.1/35728

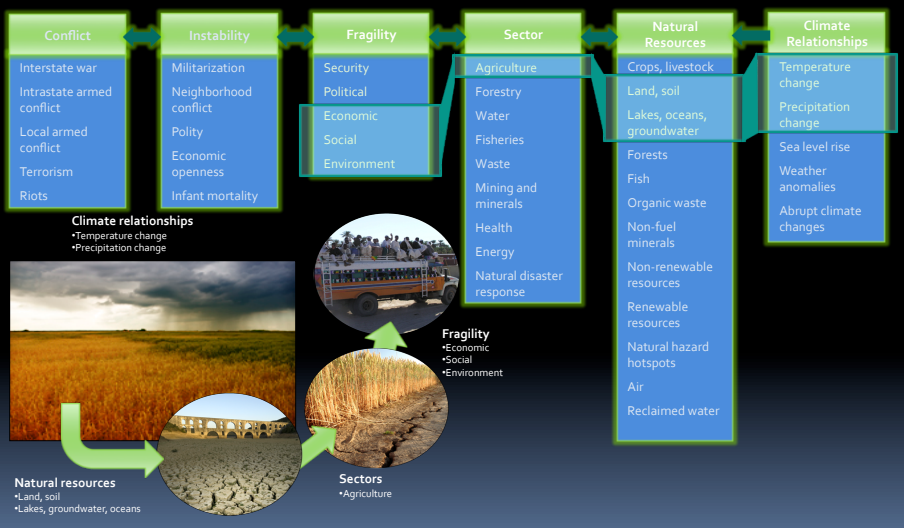
Climate change and stability

- *Example*: Recent work has suggested a relationship between the occurrence of El Nino and conflict – perhaps a contributing factor in 21% of all civil conflicts since 1950#
- *Example*: Other work focused on the relationship between climate and conflict in Africa has concluded that small increases in temperature (1C) measurably increase the incidence of civil war##
- *Example*: Climate change is believed to have been a contributing factor to the conflict in Darfur.**

$$\text{Vulnerability}^* = \frac{\text{(stress) x (sensitivity)}}{\text{(adaptive capacity)}}$$

Hsiang et al, *Nature*, Vol. 476, 25 August 2011, pp. 438 - 441.
Burke et al, *Proc. Natl. Acad. Sci.*, vol. 106, no. 49, 20670-20674 (2009).
* Based upon: Adger, *Global Environmental Change*, 16 (2006) 268–281.
** United Nations Environment Programme, *Sudan: Post-Conflict Environmental Assessment*, 2007.

Proposed architecture relating climate effects to conflict*



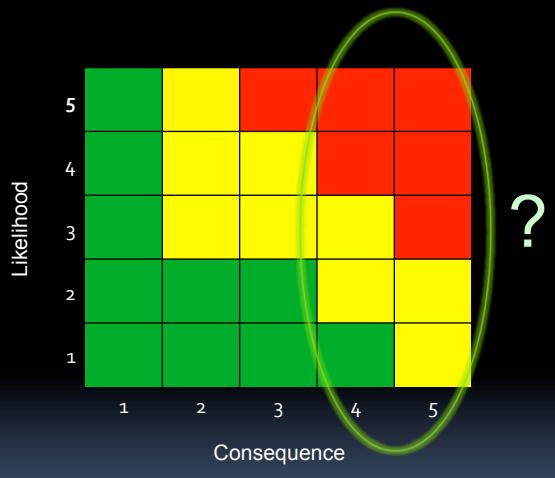
*Alcorn *et al*, "Environmental Change and Fragile States - Early Warning Needs, Opportunities, & Intervention", Logistics Management Institute report for Army Environmental Policy Institute, Figure 6-3, September 2011. Reproduced with permission.

Potential climate change impacts on key source countries

Country	Resources	Potential Climate Change Impacts
Brazil	Nb	Drought in northeast leading to internal migration, influx of migrants from neighboring countries[$]
China	Mo, W, Ti, V	Drought/desertification and reduced runoff from Himalayan glaciers reduce agricultural production and cause internal migration; stress with neighboring countries; expanded area susceptible to malaria*
Kazakhstan	Cr	Water stress, possible influx of migrants[#]
Republic of Congo	Co	Water stress, reduced agricultural capacity[@]
Russia	V	Societal and political challenges – including migration[##]
South Africa	Cr, V	Reduced rainfall results in reduced agricultural production**

[$] Carson, "Brazil" in *Climate Change and National Security – A Country-Level Analysis*, D. Moran, ed., Georgetown University Press, 2011.
[*] Lewis, *International Affairs*, 85:6 (2009), pp. 1195 – 1213 and National Intelligence Council, CR 2009-09, June 2009.
[#] Schatz, "Central Asia" in *Climate Change and National Security – A Country-Level Analysis*, D. Moran, ed., Georgetown University Press, 2011.
[@] UNFCCC, *Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries*, 2007.
[##] Wallander, "Russia" in *Climate Change and National Security – A Country-Level Analysis*, D. Moran, ed., Georgetown University Press, 2011.
[**] Brown *et al*, *International Affairs*, 83:6 (2007), pp. 1141 – 1154.

Risk domain



The consequence of lack of availability for all elements is very serious. The only variable is likelihood.

Risk Mitigation

(in decreasing order of feasibility and effectiveness)

- Enhance the adaptability to climate change of source countries
- Arrest climate change
- Reduce demand by use of more efficient manufacturing processes
- Recycle
- Stockpile
- Find alternative sources in new, less vulnerable locations
- Identify substitutes

Summary

- Modern aerospace systems rely on engineering alloys with carefully tailored compositions.
- Although most of the critical alloying elements are not in short supply, many come from countries that could be vulnerable to climate change.
- There is a possibility that the stability of these countries could be negatively impacted and lead to disruptions in the availability of the critical materials.
- Impact of potential mitigation approaches may be limited.